EVALUATION OF FIRE-CONTROL POLICY BY HYBRID COMPUTER SIMULATION

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United States Naval Postgraduate School

THESIS

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Evaluation of Fire-Control Policy

by Hybrid Computer Simulation

by

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ABSTRACT

A real-time hybrid computer simulation was constructed for the study of fire-control pattern effectiveness in the defense of a destroyer against PT-boat attack. Different spotting procedures were tried over a repeatable maneuvering and non-maneuvering track in order to evaluate the relative results. The simulation also had a two-player gaming capability in order to evaluate the spotting procedures under full-scale evasion tactics. It was found that normal dispersion is more effective than random area fire for a low-speed maneuvering target, but area fire was more effective for a high-speed maneuvering target, with a random area fire the most effective.

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I. INTRODUCTION

The probability of hitting a fixed point at long ranges with a conventional ballistic projectile is not very high. When the target becomes a maneuvering object the probability drops even more due to the distance that can be traveled while the projectile is in flight. If the target is to be considered a highly maneuverable PT boat that is capable of launching a torpedo against own ship, it would be most desirable to hit the PT boat beyond the weapons release range (hereafter referred to as W. R. range) of the PT boat. Own ship, in this case, is considered to be a DD type vessel with conventional guns.

The purpose of this study is to improve the hit probability at long ranges, using conventional weapons, against a maneuvering target. This may be achieved with spotting doctrines, some type of tracking filter, or a combination of the two.

Previous work has already been done in this area. Demetry [1] has done an all-digital computer simulation of tracking capabilities. He evaluated two different digital filters against a maneuvering and a non-maneuvering target track. The result was a suggested scheme that would employ two different trackers: a short-term (hereafter referred to as ST) and a long-term (hereafter referred to as LT) tracker. Switching would be done between the two trackers when maneuvers were detected. The ST tracker was a Kalman filter with a precomputed gain schedule. This would be used for the non-maneuvering situation. The LT tracker was a least-squares fit to forty consecutive pieces of radar data. This tracker would be used while a maneuver was in progress to determine a base course for a zigzag track.

Smith [2] has done a hydrid computer real-time simulation of the DD firing at the PT boat, which goes one step farther by checking the predicting capabilities of a tracker and/or spotting routine. His simulation included acceleration-limited vessels that were able to operate at different courses and speeds. The PT boat was able to maneuver while the DD was firing at it. The projectile's predicted impact position had normal dispersion added. Resulting fire accuracy was comparable to actual real-life results. By using a standard track, different spotting procedures were evaluated by comparing results. Smith has recommended the incorporation of two spotting procedures into one adaptive policy. For a non-maneuvering target no spot is used. For a maneuvering target, a random area fire spot is introduced.

The present study employs Smith's basic model with modifications. Various parameters were varied in the tracker to observe what results, if any, they had on the hitting accuracy. Different spotting patterns were evaluated by comparing them against no spots for the same track. A gaming mode has been added so that the PT skipper can actually maneuver the PT boat at will and the DD skipper can select pre-programmed spotting routines at will.

II. TRACKER MODIFICATIONS

The tracker in this simulation was conceived by Demetry [1] and evaluated by Smith [2]. The basic concept was accepted as being valid. Various parameters were varied in order to see what effect they had on tracking quality as indicated by the hitting accuracy.

The tracker basically consists of two digital filters. The ST tracker was a Kalman filter with one measured quantity, range. The gain schedule is truncated at thirty seconds. Four pieces of data are stored for the ST track so that when a maneuver is detected, reprocessing is done on the last four pieces of data, using the initial values of the gain schedule. Normally, on a settled track, considerable weight is placed on old data, but initially the weight is placed on the new data. The LT filter is a least-squares fit to forty consecutive pieces of data. The selection criterion between short or long-term tracking depended upon the detection of a maneuver. If a maneuver was detected, the LT tracker was used; if not, the ST tracker was used. The criterion for maneuver detection was two successive differences between predicted position and measured position of greater than or equal to forty yards and of the same sign.

The manuever detection is quite important. If a false maneuver is detected, the range prediction will be in error until the velocity settles down again. If a maneuver goes undetected, the range prediction will be in error unless the filter can follow the velocity change as it occurs, thus giving the correct predicted position.

The first parameter varied was the maneuver detector or reprocessing criterion. A straight, pure range-rate track was chosen. There were no maneuvers conducted. Results were judged by observing the maneuver-detector light (this was a false alarm) and observing the miss distance statistics for a no-spot firing run. The first run (Fig. II-1 Run 1) used the LT tracker only to insure that there was no bias in the spot routine. The next runs (Fig. II-1 Tun 2 to 5) consisted of increasing the value of the reprocessing criterion from sixty yards to eighty yards. Sixty-five yards was the first value not to have a maneuver detection indication for a straight track. The miss distance statistics, for the straight track, were about the same from sixty-five to eighty yards.

As the next step, a maneuvering run was chosen in order to observe the effects. On these runs (Fig. II-1 Runs 6 to 8) the miss distances increased as the reprocessing criterion was increased, as expected. Sixty-five yards was chosen as the reprocessing criterion; below this value the false-alarm rate was not acceptable and above it the miss distances would be larger for a maneuvering target.

The number of measurements, after a maneuver is detected, for which the LT tracker is used before switching back to the ST tracker was also a parameter considered. Reprocessing in the ST tracker accounts for three observations. In previous work [2] the LT tracker was used for one observation after reprocessing. It can, however, be used for more observations before switching back to the ST tracker. To see what effect this had on hit quality, the LT tracker was used for a different number of observations before switching back to the ST tracker. The number of observations was varied from reprocessing plus three to reprocessing plus nine for this test. Results were observed as miss-distance statistics on the same maneuvering track. The miss distances decreased (Fig. II-1 Runs 9 to 16) as the holding time was increased up until reprocessing-plus-six observations, then started increasing again. The velocity output of the ST tracker takes approximately nine observations for the magnitude of the ST and LT velocity outputs to be equal. This would explain the initial decrease in error. The position output of the LT tracker is sluggish to maneuvers as compared to the ST tracker. After some measurements on a new course there would be a difference in position between the LT and ST tracker. The ST would be more nearly correct since it is more responsive to fresh data. This would explain the increase in error after nine observations. The tracker was modified to include the hold on the LT tracker for reprocessing plus six, or a total of nine pieces of data out of the ST tracker, before switching back.

The next step was to consider a combination output from the tracker. The preceding step showed that position was more accurate from the ST and velocity more accurate from the LT in a maneuvering situation. For this run, when a maneuver was detected the velocity output of the LT tracker was used and the position output of the ST tracker was used for reprocessing-plus-six observations. The results (Fig. II-1 Run 17) show an improvement over the earlier runs.

The final consideration was whether the reprocessing rate was a function of relative velocity. Successive absolute values of difference between predicted position and measured position were recorded (Fig. II-2). Relative velocity was varied from five yards per second to thirty yards per second. No differences were observed in the output. For a non-maneuvering target, if there were a difference between predicted position and measured position it would be due to measurement noise. The fact that measurement noise is not a function of velocity (in this simulation) would explain the results.

In summary, the modifications made to the tracker include:

1. Changing the reprocessing criterion to two successive prediction errors of greater than or equal to DETR and of the same sign

where
$$\text{DETR} = \begin{cases} 65 & 15\text{K} < \text{Range} \le 20\text{K} \\ 60 & \text{Range} \le 15\text{K} \end{cases}$$
yards

2. The number of measurements, after reprocessing, before the tracker is switched back to the short term tracker is now six.

3. After a maneuver is detected and reprocessing occurs, position is used from the ST tracker and velocity is used from the LT tracker.

RUN NUMBER	RELATIVE VELOCITY	NUMBER OF OBS. AFTER REPROCESS	DETR (yd)	AVERAGE MISS DISTANCE X (yd)	X (yd)	R (yd)
1	60		60	1.	1.	45.
2	60	1	60	-91.	-62.	190.
3	60	1	65	-4.	-13.	50.
4	60	1	70	12.	6.	52.
5	60	1	80	9.	-6.	47.
6	60	1	65	11.	-105.	234.
7	60	1	70	-3.	-45.	312.
8	60	1	80	36.	-81.	307.
9	60	3	65	18.	-64.	277.
10	60	4	65	39.	-72.	335.
11	60	5	65	21.	-79.	278.
12	60	6	65	12.	-52.	272.
13	60	6	65	8.	-53.	231.
14	60	7	65	50.	-93.	306.
15	60	8	65	66.	-95.	236.
16	60	9	65	66.	-108.	286.
17	60	6	65	35.	-68.	257.

Fig. II-1 Tracker modification tests

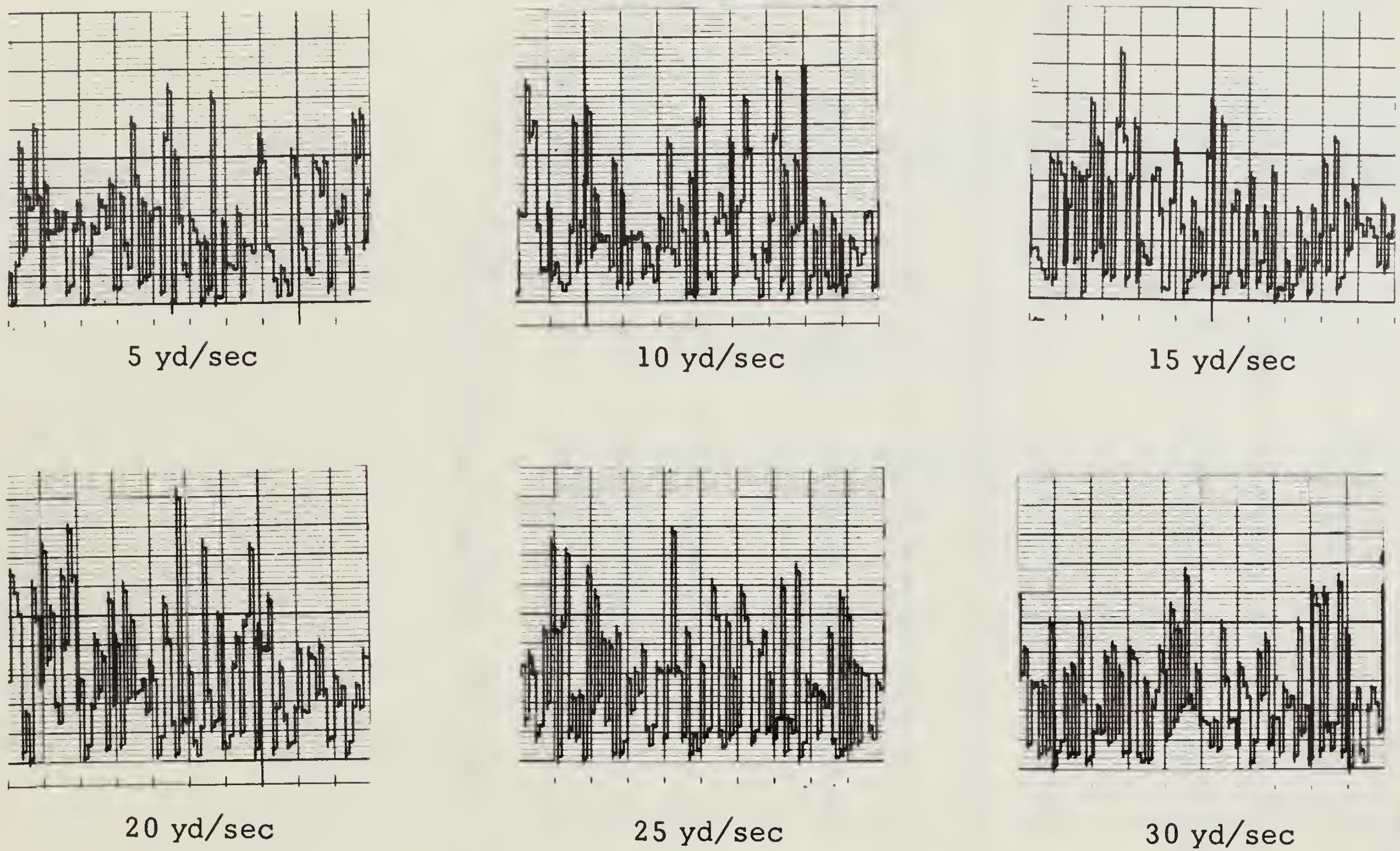


Fig. II-2 Reprocessing test for various relative velocities

III. SPOTTING PROCEDURES

Projectile fire may qualitatively be characterized as either point fire or area fire. In point fire no spot is used and the fire is aimed directly at the target. In area fire the concept is to define an area around the target and distribute the rounds in this area in some manner. The normal way of accomplishing this is to predict the actual position of the target and then add a spot to it. The ballistics will then be calculated for the fall of shot to land in an area around the predicted position rather than at the predicted position. This is especially useful for a situation where the actual location is not known with high certainty, such as in a maneuvering situation.

One of the area-spotting procedures in general use is known as a rocking ladder. There is a value for a range spot and one for a bearing spot. The range spot will be added in one instance, not used in the second, then subtracted in the third. The bearing spot will be subtracted for a right spot, not used, and then added for a left spot. Combining these two spots gives nine different discrete points to fire at in an area. The normal dispersion of the fall of shot will spread these points slightly also.

Another way of achieving area fire is to add a random spot to the measured point. In this way the fall of shot would be distributed according to the probability distribution function of the random spot used.

In order to observe the spotting pattern of the normal and uniform distribution functions, a computer program was written. A point was defined: in polar coordinates, $R1 = 17{,}500$ yards, $\theta = 45°$; in rectangular coordinates $RX1 = R1 \cos \theta$, $RY1 = R1 \sin \theta$. The different combinations of normal and uniform spots were added to the polar quantities and then resolved and stored as rectangular quantities. Each combination of distributions had one thousand spots added to the initial point, after which a plot was made of the results. The results (Fig. III-1 to 4) are for spots of the following magnitudes:

$$-100 \leq RSPOT \leq 100 \quad \text{yards}$$

$$-.0049 \leq BSPOT \leq .0049 \quad \text{radians}$$

In the figures, the circle has a one-hundred-hard radius and the plus sign marks the defined point.

This simulation evaluated the rocking-ladder concept as spotting procedure one and a uniform range spot with a normal bearing spot as spotting procedure three.

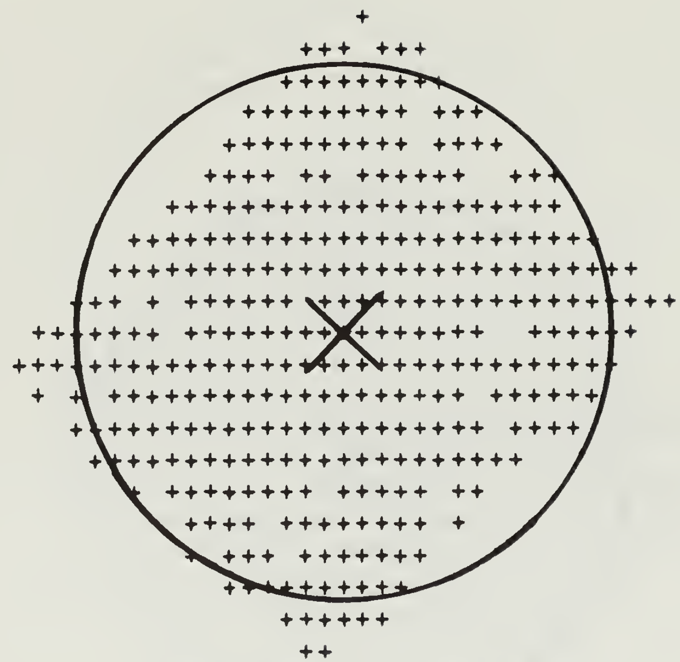


Fig. III-1 RSPOT - uniform   BSPOT - uniform

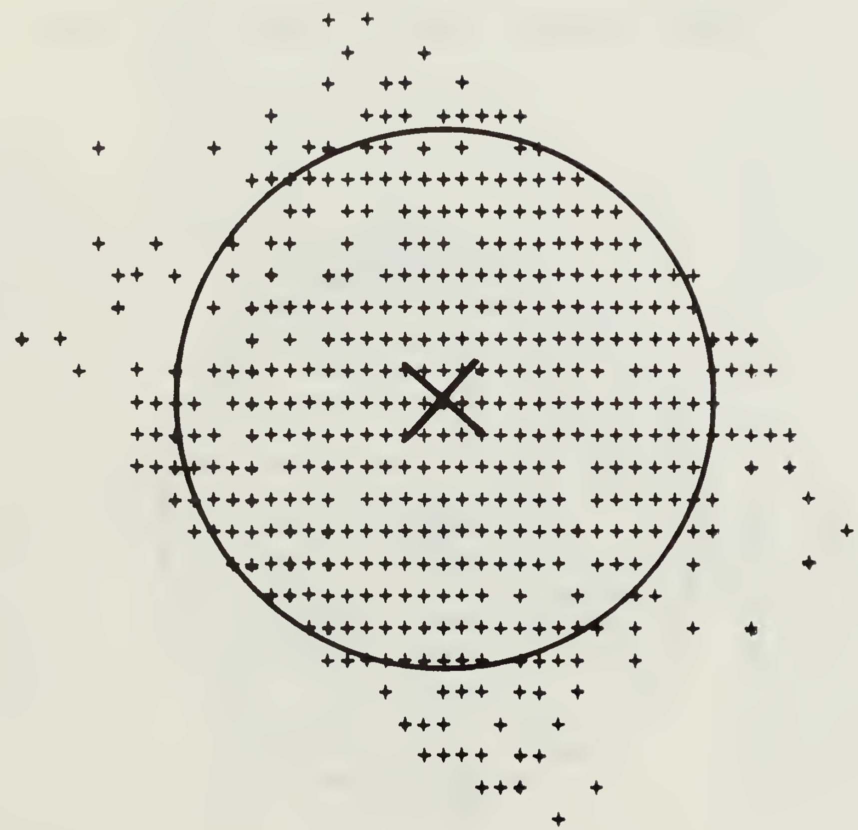


Fig. III-2 RSPOT - uniform BSPOT - normal

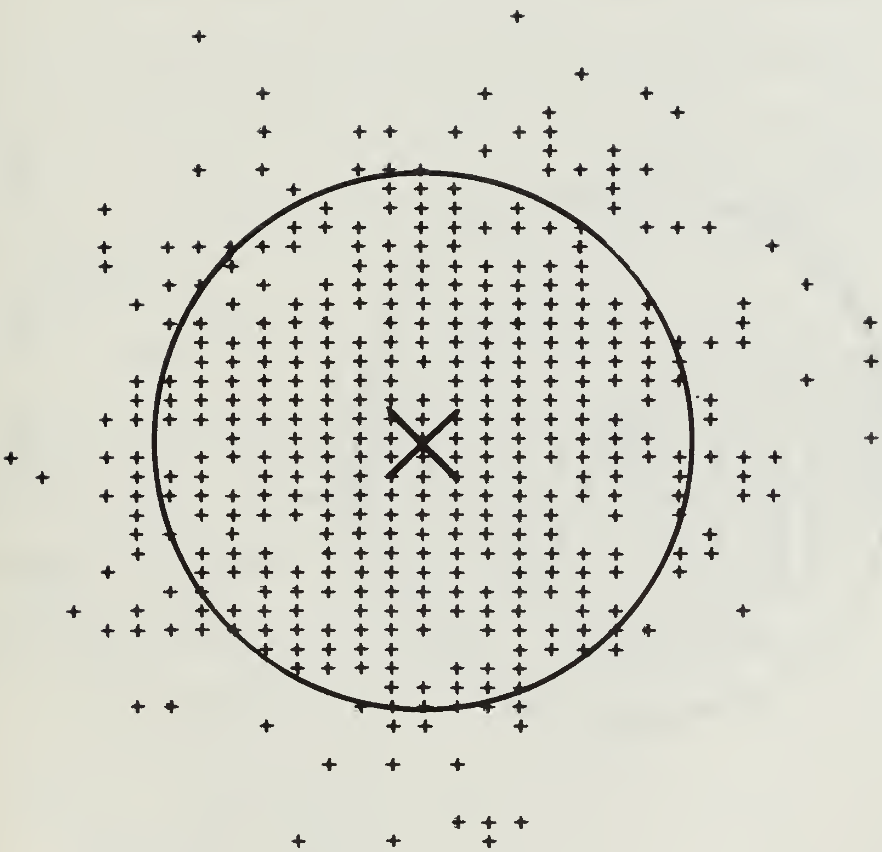


Fig. III-3 RSPOT - normal BSPOT - normal

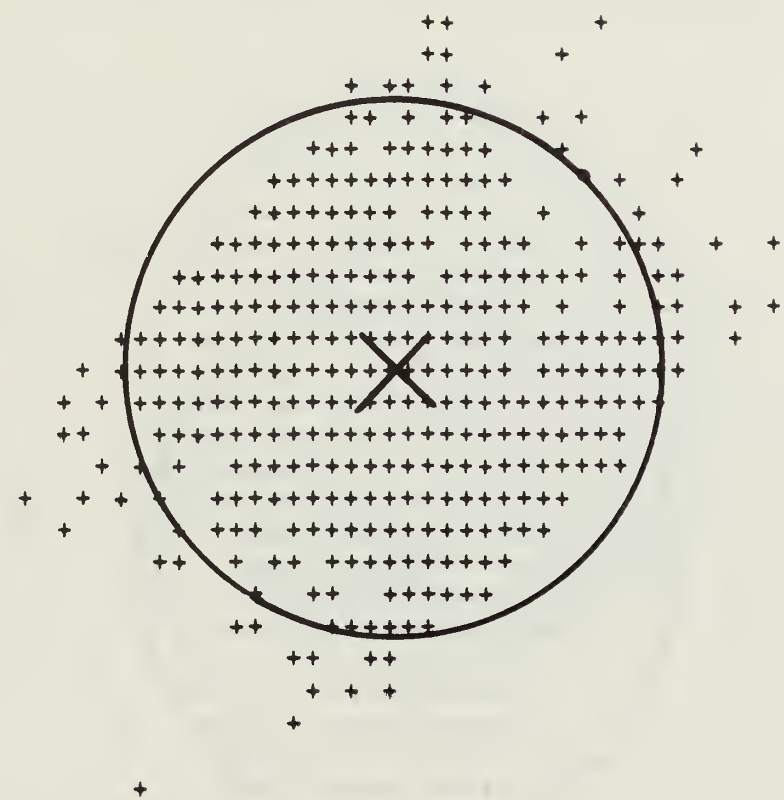


Fig. III-4 RSPOT - normal   BSPOT - uniform

IV. GAMING

The gaming mode of this simulation allowed the spotting procedures to be evaluated against a target that was maneuvered by a man rather than by a pre-programmed set of maneuver instructions.

The destroyer skipper had a non-maneuvering vessel that could open fire on the PT boat before the PT boat could release his torpedo. He could select any one of four spotting doctrines and change these as the run progressed. He could fire continuously or in bursts at the rate of twenty rounds per minute.

The PT skipper had a maneuvering vessel that could launch a torpedo against the destroyer with a ten-thousand-yard-run capability. His main asset was maneuverability, since the incoming round had approximately forty seconds in flight from firing to impact.

The initial conditions for the runs were as follows:

RX1 - 16,000 yards

RY1 - 16,000 yards

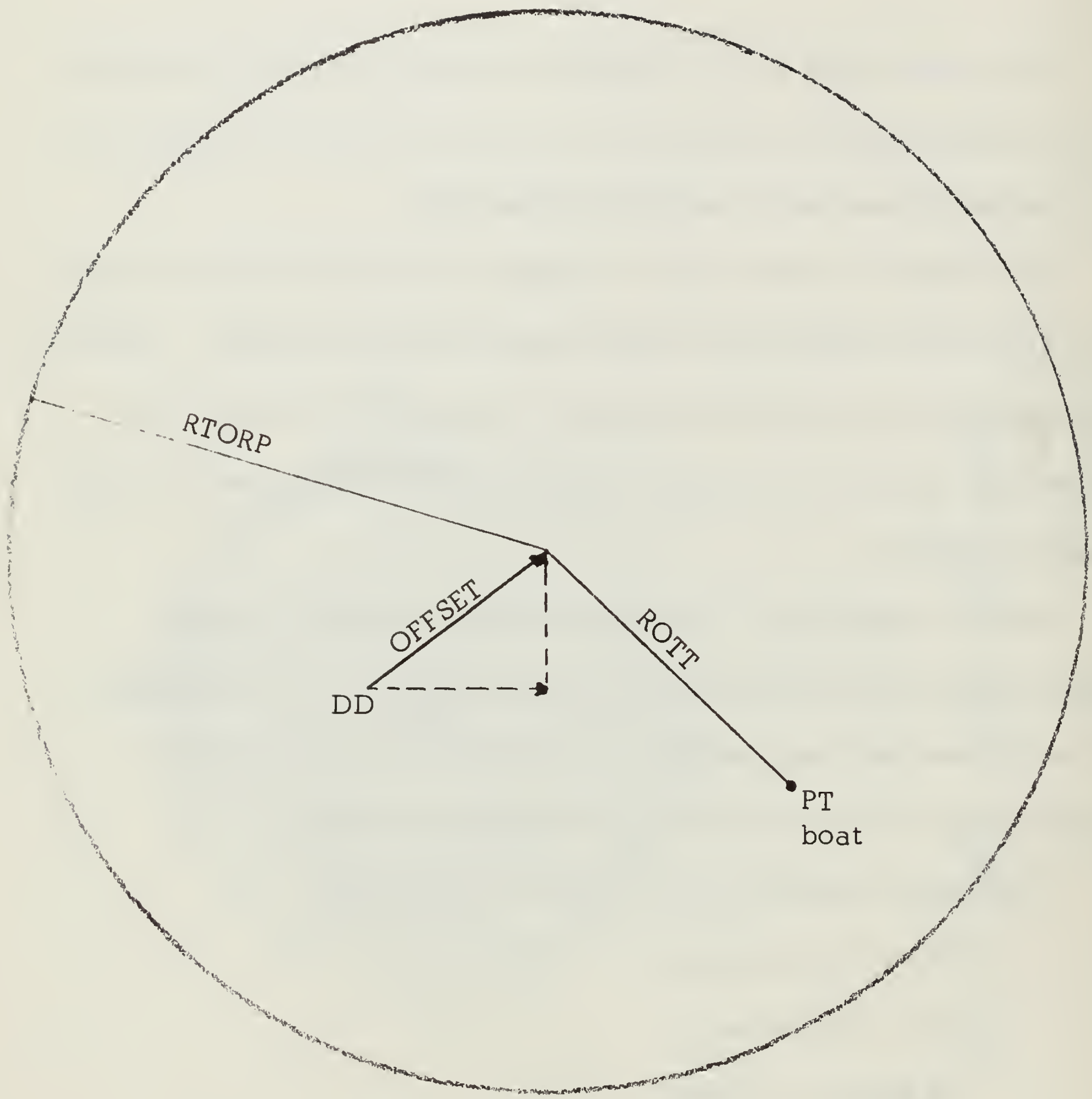
PT Speed - 30 knots
Course - 045°

DD Speed - 20 knots
Course - 225°

Win Criteria

DD - one hit (miss distance R = 40 yards)

PT - penetration to W R envelope (Fig. IV-1)



RTORP - Maximum range of torpedo

OFFSET - Distance DD can travel, at present speed, after torpedo is launched

ROTT - actual torpedo run distance

Fig. IV-1 Weapons release circle

V. RESULTS

In order to evaluate the hitting accuracy of the spotting procedures, three different tracks were chosen. The tracks were selected for high range rate, high bearing rate and mixed range and bearing rates. The runs were conducted with and without maneuvers. Target speed was varied from twenty to fifty knots in ten-knot increments. This gave a total of twenty-four different runs. These runs were repeated for each spotting mode, giving a total of ninety-six runs. There were approximately one thousand rounds fired for each spotting mode with maneuvers and one thousand rounds for each spotting mode without maneuvers. All rounds were fired with impact range between fifteen and twenty thousand yards.

A description of the tracks:

TRACK I - High Range Rate

DD - 20 knots

PT - 20,30,40,50 knots

Initial Conditions

RX - 16,000
RY - 16,000

TRACK II - High Bearing Rate

DD - 20 knots

PT - 20,30,40,50 knots

Initial Conditions

RX - 12,000
RY - 16,000

TRACK III - Mixed

DD - 20 knots

PT - 20,30,40,50 knots

Initial Conditions

RX - 16,000
RY - 12,000

The spotting modes are described as follows:

Spot 1 - Rocking Ladder - discrete area fire. The range spot was +100, 0, - 100 yards. The bearing spot +.0049, 0., - .0049 radians.

Spot 2 - No spot.

Spot 3 - Random area fire - uniform spot in range with spread from +100 to -100 yards. Normal spot in bearing with zero mean and standard deviation equal to .0098 radians.

Spot 4 - Adaptive spot - if a maneuver is detected, use random spot; if not, use no spot.

The statistics of the spot evaluation mode (Fig. V-1 to 10) are subdivided first into two categories: non-maneuvering and maneuvering. The overall non-maneuvering (Fig. V-1) and maneuvering (Fig. V-6). The results are next subdivdied into categories of PT speed and non-maneuvering (Fig. V-2 to 5) and maneuvering (Fig. V-7 to 10).

The probability of hitting a non-maneuvering target is not velocity dependent. The results (Fig. V-11) indicate the normal dispersion of a no-spot doctrine to be as effective as the discrete area fire and more effective than the random area fire. The area of likelihood of target location is small and adequately covered with normal dispersion. The low mean miss distances indicate non-biased spotting routines.

In all maneuvering track cases (Fig. V-12), as PT speed increased the hitting accuracy decreased. This was to be expected as the area of likelihood of target location increases with target speed. In the two lower-speed cases the probability of a hit was higher with point fire than with area fire.

For a higher target speed the area fire gave the best results. The interpretation is that normal dispersion is the best "pattern" until the area of possible target location is much greater than that covered by normal dispersion.

The large mean Y miss distance for Spot 1, which was consistent throughout the evaluation of maneuvering targets, cannot be explained. It is not a fault of the basic spotting routine as it would also show up in the non-maneuvering runs.

A. GAMING MODE

There were not enough runs actually made with the gaming mode to properly evaluate any spotting scheme in this context.

Certain modifications will have to be made to the timing system or the ground rules for the gaming mode. With a number of rounds in the air at one time and with a highly maneuvering PT boat, it is possible to have one round fired and splash before an earlier round splashes. This is not compatible with a timing system that assumes first fired, first splashed, as is the case in the present simulation.

```
OVERALL RESULTS FOR NON-MANEUVERING PT BOAT WITH SPOTTING MODE 1

  AVER X MISS DIST =    5.53   MEAN SQ X MISS DIST=   2384.   VAR X MISS DIST =   2354.
  AVER Y MISS DIST =   -3.95   MEAN SQ Y MISS DIST=   1769.   VAR Y MISS DIST =   1753.
  AVER R MISS DIST =   54.31   MEAN SQ R MISS DIST=   4153.   VAR R MISS DIST =   1203.
  PERCENT OF HITS =39.16   NUMBER OF ROUNDS FIRED =  950

OVERALL RESULTS FOR NON-MANEUVERING PT BOAT WITH SPOTTING MODE 2

  AVER X MISS DIST =    4.13   MEAN SQ X MISS DIST=   2227.   VAR X MISS DIST =   2210.
  AVER Y MISS DIST =   -3.21   MEAN SQ Y MISS DIST=   2032.   VAR Y MISS DIST =   2022.
  AVER R MISS DIST =   53.32   MEAN SQ R MISS DIST=   4259.   VAR R MISS DIST =   1417.
  PERCENT OF HITS =38.88   NUMBER OF ROUNDS FIRED =  949

OVERALL RESULTS FOR NON-MANEUVERING PT BOAT WITH SPOTTING MODE 3

  AVER X MISS DIST =   -3.87   MEAN SQ X MISS DIST=   8849.   VAR X MISS DIST =   8834.
  AVER Y MISS DIST =    3.13   MEAN SQ Y MISS DIST=   5169.   VAR Y MISS DIST =   5159.
  AVER R MISS DIST =   94.23   MEAN SQ R MISS DIST=  14018.   VAR R MISS DIST =   5138.
  PERCENT OF HITS =15.51   NUMBER OF ROUNDS FIRED =  935

OVERALL RESULTS FOR NON-MANEUVERING PT BOAT WITH SPOTTING MODE 4

  AVER X MISS DIST =    2.15   MEAN SQ X MISS DIST=   2686.   VAR X MISS DIST =   2681.
  AVER Y MISS DIST =    -.18   MEAN SQ Y MISS DIST=   2265.   VAR Y MISS DIST =   2265.
  AVER R MISS DIST =   55.07   MEAN SQ R MISS DIST=   4951.   VAR R MISS DIST =   1918.
  PERCENT OF HITS =38.28   NUMBER OF ROUNDS FIRED =  951
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Fig. V-1 Overall results for non-maneuvering PT boat

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RESULTS FOR NON-MANEUVERING PT BOAT WITH SPEED = 20 KNOTS AND SPOTTING MODE 1

  AVER X MISS DIST =    4.52   MEAN SQ X MISS DIST=   1853.   VAR X MISS DIST =   1832.
  AVER Y MISS DIST =   -3.72   MEAN SQ Y MISS DIST=   1503.   VAR Y MISS DIST =   1489.
  AVER R MISS DIST =   51.21   MEAN SQ R MISS DIST=   3355.   VAR R MISS DIST =    733.
  PERCENT OF HITS =38.58   NUMBER OF ROUNDS FIRED =  324

RESULTS FOR NON-MANEUVERING PT BOAT WITH SPEED = 20 KNOTS AND SPOTTING MODE 2

  AVER X MISS DIST =   -1.32   MEAN SQ X MISS DIST=   1983.   VAR X MISS DIST =   1981.
  AVER Y MISS DIST =   -2.08   MEAN SQ Y MISS DIST=   1426.   VAR Y MISS DIST =   1422.
  AVER R MISS DIST =   51.34   MEAN SQ R MISS DIST=   3410.   VAR R MISS DIST =    774.
  PERCENT OF HITS =37.30   NUMBER OF ROUNDS FIRED =  319

RESULTS FOR NON-MANEUVERING PT BOAT WITH SPEED = 20 KNOTS AND SPOTTING MODE 3

  AVER X MISS DIST =   -5.49   MEAN SQ X MISS DIST=   4973.   VAR X MISS DIST =   4943.
  AVER Y MISS DIST =    4.50   MEAN SQ Y MISS DIST=   5034.   VAR Y MISS DIST =   5013.
  AVER R MISS DIST =   83.91   MEAN SQ R MISS DIST=  10007.   VAR R MISS DIST =   2966.
  PERCENT OF HITS =18.63   NUMBER OF ROUNDS FIRED =  322

RESULTS FOR NON-MANEUVERING PT BOAT WITH SPEED = 20 KNOTS AND SPOTTING MODE 4

  AVER X MISS DIST =    4.80   MEAN SQ X MISS DIST=   2062.   VAR X MISS DIST =   2039.
  AVER Y MISS DIST =   -5.38   MEAN SQ Y MISS DIST=   1908.   VAR Y MISS DIST =   1879.
  AVER R MISS DIST =   53.91   MEAN SQ R MISS DIST=   3970.   VAR R MISS DIST =   1063.
  PERCENT OF HITS =36.53   NUMBER OF ROUNDS FIRED =  323
```

Fig. V-2 Results for non-maneuvering PT boat with speed of 20 knots

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RESULTS FOR NON-MANEUVERING PT BOAT WITH SPEED = 30 KNOTS AND SPOTTING MODE 1

  AVER X MISS DIST =    7.78   MEAN SQ X MISS DIST=   1799.   VAR X MISS DIST =   1739.
  AVER Y MISS DIST =   -7.10   MEAN SQ Y MISS DIST=   1459.   VAR Y MISS DIST =   1409.
  AVER R MISS DIST =   50.22   MEAN SQ R MISS DIST=   3258.   VAR R MISS DIST =    737.
  PERCENT OF HITS =40.80   NUMBER OF ROUNDS FIRED =  250

RESULTS FOR NON-MANEUVERING PT BOAT WITH SPEED = 30 KNOTS AND SPOTTING MODE 2

  AVER X MISS DIST =    5.11   MEAN SQ X MISS DIST=   2505.   VAR X MISS DIST =   2479.
  AVER Y MISS DIST =   -1.90   MEAN SQ Y MISS DIST=   1713.   VAR Y MISS DIST =   1709.
  AVER R MISS DIST =   53.10   MEAN SQ R MISS DIST=   4217.   VAR R MISS DIST =   1398.
  PERCENT OF HITS =37.94   NUMBER OF ROUNDS FIRED =  253

RESULTS FOR NON-MANEUVERING PT BOAT WITH SPEED = 30 KNOTS AND SPOTTING MODE 3

  AVER X MISS DIST =    1.54   MEAN SQ X MISS DIST=   7497.   VAR X MISS DIST =   7494.
  AVER Y MISS DIST =    4.89   MEAN SQ Y MISS DIST=   5384.   VAR Y MISS DIST =   5361.
  AVER R MISS DIST =   95.65   MEAN SQ R MISS DIST=  12881.   VAR R MISS DIST =   3731.
  PERCENT OF HITS =12.05   NUMBER OF ROUNDS FIRED =  249

RESULTS FOR NON-MANEUVERING PT BOAT WITH SPEED = 30 KNOTS AND SPOTTING MODE 4

  AVER X MISS DIST =   -2.38   MEAN SQ X MISS DIST=   3021.   VAR X MISS DIST =   3015.
  AVER Y MISS DIST =    8.42   MEAN SQ Y MISS DIST=   2687.   VAR Y MISS DIST =   2616.
  AVER R MISS DIST =   55.97   MEAN SQ R MISS DIST=   5708.   VAR R MISS DIST =   2575.
  PERCENT OF HITS =41.20   NUMBER OF ROUNDS FIRED =  250
```

Fig. V-3 Results for non-maneuvering PT boat with speed of 30 knots

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RESULTS FOR NON-MANEUVERING PT BOAT WITH SPEED = 40 KNOTS AND SPOTTING MODE 1

  AVER X MISS DIST =    5.41   MEAN SQ X MISS DIST=   3181.   VAR X MISS DIST =   3152.
  AVER Y MISS DIST =    1.27   MEAN SQ Y MISS DIST=   1583.   VAR Y MISS DIST =   1581.
  AVER R MISS DIST =   57.46   MEAN SQ R MISS DIST=   4764.   VAR R MISS DIST =   1462.
  PERCENT OF HITS =38.54   NUMBER OF ROUNDS FIRED =  205

RESULTS FOR NON-MANEUVERING PT BOAT WITH SPEED = 40 KNOTS AND SPOTTING MODE 2

  AVER X MISS DIST =    2.81   MEAN SQ X MISS DIST=   1895.   VAR X MISS DIST =   1887.
  AVER Y MISS DIST =    -.77   MEAN SQ Y MISS DIST=   1548.   VAR Y MISS DIST =   1548.
  AVER R MISS DIST =   50.50   MEAN SQ R MISS DIST=   3444.   VAR R MISS DIST =    893.
  PERCENT OF HITS =45.15   NUMBER OF ROUNDS FIRED =  206

RESULTS FOR NON-MANEUVERING PT BOAT WITH SPEED = 40 KNOTS AND SPOTTING MODE 3

  AVER X MISS DIST =   16.83   MEAN SQ X MISS DIST=   5426.   VAR X MISS DIST =   5143.
  AVER Y MISS DIST =    4.33   MEAN SQ Y MISS DIST=   4876.   VAR Y MISS DIST =   4858.
  AVER R MISS DIST =   86.63   MEAN SQ R MISS DIST=  10302.   VAR R MISS DIST =   2797.
  PERCENT OF HITS =14.07   NUMBER OF ROUNDS FIRED =  199

RESULTS FOR NON-MANEUVERING PT BOAT WITH SPEED = 40 KNOTS AND SPOTTING MODE 4

  AVER X MISS DIST =   -3.00   MEAN SQ X MISS DIST=   2644.   VAR X MISS DIST =   2635.
  AVER Y MISS DIST =    2.97   MEAN SQ Y MISS DIST=   1789.   VAR Y MISS DIST =   1780.
  AVER R MISS DIST =   55.99   MEAN SQ R MISS DIST=   4433.   VAR R MISS DIST =   1299.
  PERCENT OF HITS =37.68   NUMBER OF ROUNDS FIRED =  207
```

Fig. V-4 Results for non-maneuvering PT boat with speed of 40 knots

```
RESULTS FØR NØN-MANEUVERING PT BØAT WITH SPEED = 50 KNØTS AND SPØTTING MØDE 1

  AVER X MISS DIST =    4.32   MEAN SQ X MISS DIST=   3291.   VAR X MISS DIST =    3273.
  AVER Y MISS DIST =   -6.08   MEAN SQ Y MISS DIST=   2948.   VAR Y MISS DIST =    2911.
  AVER R MISS DIST =   62.42   MEAN SQ R MISS DIST=   6240.   VAR R MISS DIST =    2344.
  PERCENT ØF HITS =38.60   NUMBER ØF RØUNDS FIRED =  171

RESULTS FØR NØN-MANEUVERING PT BØAT WITH SPEED = 50 KNØTS AND SPØTTING MØDE 2

  AVER X MISS DIST =   14.44   MEAN SQ X MISS DIST=   2672.   VAR X MISS DIST =    2463.
  AVER Y MISS DIST =  -10.19   MEAN SQ Y MISS DIST=   4219.   VAR Y MISS DIST =    4115.
  AVER R MISS DIST =   60.71   MEAN SQ R MISS DIST=   6890.   VAR R MISS DIST =    3205.
  PERCENT ØF HITS =35.67   NUMBER ØF RØUNDS FIRED =  171

RESULTS FØR NØN-MANEUVERING PT BØAT WITH SPEED = 50 KNØTS AND SPØTTING MØDE 3

  AVER X MISS DIST =  -33.84   MEAN SQ X MISS DIST=  22580.   VAR X MISS DIST =   21436.
  AVER Y MISS DIST =   -3.61   MEAN SQ Y MISS DIST=   5462.   VAR Y MISS DIST =    5449.
  AVER R MISS DIST =  121.39   MEAN SQ R MISS DIST=  28043.   VAR R MISS DIST =   13308.
  PERCENT ØF HITS =16.36   NUMBER ØF RØUNDS FIRED =  165

RESULTS FØR NØN-MANEUVERING PT BØAT WITH SPEED = 50 KNØTS AND SPØTTIN. MØDE 4

  AVER X MISS DIST =    9.97   MEAN SQ X MISS DIST=   3426.   VAR X MIS  DIST =    3327.
  AVER Y MISS DIST =   -6.76   MEAN SQ Y MISS DIST=   2901.   VAR Y MISS DIST =    2855.
  AVER R MISS DIST =   54.85   MEAN SQ R MISS DIST=   6326.   VAR R MISS DIST =    3317.
  PERCENT ØF HITS =38.01   NUMBER ØF RØUNDS FIRED =  171
```

Fig. V-5 Results for non-maneuvering PT boat with speed of 50 knots

```
OVERALL RESULTS FOR MANEUVERING PT BOAT WITH SPOTTING MODE 1

  AVER X MISS DIST =  -18.17   MEAN SQ X MISS DIST=  12609.   VAR X MISS DIST =  12279.
  AVER Y MISS DIST =   88.47   MEAN SQ Y MISS DIST=  73951.   VAR Y MISS DIST =  66123.
  AVER R MISS DIST =  237.71   MEAN SQ R MISS DIST=  86560.   VAR R MISS DIST =  30055.
  PERCENT OF HITS = 4.97   NUMBER OF ROUNDS FIRED =  966

OVERALL RESULTS FOR MANEUVERING PT BOAT WITH SPOTTING MODE 2

  AVER X MISS DIST =  -11.12   MEAN SQ X MISS DIST=  10559.   VAR X MISS DIST =  10436.
  AVER Y MISS DIST =   18.67   MEAN SQ Y MISS DIST=  65015.   VAR Y MISS DIST =  64666.
  AVER R MISS DIST =  217.27   MEAN SQ R MISS DIST=  75574.   VAR R MISS DIST =  28368.
  PERCENT OF HITS = 6.32   NUMBER OF ROUNDS FIRED =  965

OVERALL RESULTS FOR MANEUVERING PT BOAT WITH SPOTTING MODE 3

  AVER X MISS DIST =   -6.30   MEAN SQ X MISS DIST=  13959.   VAR X MISS DIST =  13919.
  AVER Y MISS DIST =  -11.79   MEAN SQ Y MISS DIST=  73742.   VAR Y MISS DIST =  73603.
  AVER R MISS DIST =  238.44   MEAN SQ R MISS DIST=  87701.   VAR R MISS DIST =  30845.
  PERCENT OF HITS = 5.32   NUMBER OF ROUNDS FIRED =  959

OVERALL RESULTS FOR MANEUVERING PT BOAT WITH SPOTTING MODE 4

  AVER X MISS DIST =  -11.69   MEAN SQ X MISS DIST=  14807.   VAR X MISS DIST =  14670.
  AVER Y MISS DIST =  -11.64   MEAN SQ Y MISS DIST=  75793.   VAR Y MISS DIST =  75657.
  AVER R MISS DIST =  235.63   MEAN SQ R MISS DIST=  90599.   VAR R MISS DIST =  35079.
  PERCENT OF HITS = 6.42   NUMBER OF ROUNDS FIRED =  966
```

Fig. V-6 Overall results for maneuvering PT boat

```
RESULTS FOR MANEUVERING PT BOAT WITH SPEED = 20 KNOTS AND SPOTTING MODE 1

  AVER X MISS DIST =  -10.43   MEAN SQ X MISS DIST=   5090.   VAR X MISS DIST =   4982.
  AVER Y MISS DIST =   90.37   MEAN SQ Y MISS DIST=  28606.   VAR Y MISS DIST =  20439.
  AVER R MISS DIST =  156.49   MEAN SQ R MISS DIST=  33697.   VAR R MISS DIST =   9206.
  PERCENT OF HITS = 7.40   NUMBER OF ROUNDS FIRED =  338

RESULTS FOR MANEUVERING PT BOAT WITH SPEED = 20 KNOTS AND SPOTTING MODE 2

  AVER X MISS DIST =  -14.28   MEAN SQ X MISS DIST=   7330.   VAR X MISS DIST =   7126.
  AVER Y MISS DIST =   -3.64   MEAN SQ Y MISS DIST=  29743.   VAR Y MISS DIST =  29730.
  AVER R MISS DIST =  149.25   MEAN SQ R MISS DIST=  37073.   VAR R MISS DIST =  14797.
  PERCENT OF HITS = 9.47   NUMBER OF ROUNDS FIRED =  338

RESULTS FOR MANEUVERING PT BOAT WITH SPEED = 20 KNOTS AND SPOTTING MODE 3

  AVER X MISS DIST =    1.16   MEAN SQ X MISS DIST=   9094.   VAR X MISS DIST =   9092.
  AVER Y MISS DIST =   -7.44   MEAN SQ Y MISS DIST=  28119.   VAR Y MISS DIST =  28063.
  AVER R MISS DIST =  156.32   MEAN SQ R MISS DIST=  37213.   VAR R MISS DIST =  12776.
  PERCENT OF HITS = 7.78   NUMBER OF ROUNDS FIRED =  334

RESULTS FOR MANEUVERING PT BOAT WITH SPEED = 20 KNOTS AND SPOTTING MODE 4

  AVER X MISS DIST =   -2.80   MEAN SQ X MISS DIST=   4594.   VAR X MISS DIST =   4587.
  AVER Y MISS DIST =  -14.89   MEAN SQ Y MISS DIST=  19294.   VAR Y MISS DIST =  19072.
  AVER R MISS DIST =  127.42   MEAN SQ R MISS DIST=  23888.   VAR R MISS DIST =   7652.
  PERCENT OF HITS =11.45   NUMBER OF ROUNDS FIRED =  332
```

Fig. V-7 Results for maneuvering PT boat with speed of 20 knots

```
RESULTS FOR MANEUVERING PT BOAT WITH SPEED = 30 KNOTS AND SPOTTING MODE 1

  AVER X MISS DIST =  -30.47   MEAN SQ X MISS DIST=  12712.   VAR X MISS DIST =  11783.
  AVER Y MISS DIST =  103.93   MEAN SQ Y MISS DIST=  54674.   VAR Y MISS DIST =  43873.
  AVER R MISS DIST =  219.93   MEAN SQ R MISS DIST=  67385.   VAR R MISS DIST =  19018.
  PERCENT OF HITS = 6.18   NUMBER OF ROUNDS FIRED =  259

RESULTS FOR MANEUVERING PT BOAT WITH SPEED = 30 KNOTS AND SPOTTING MODE 2

  AVER X MISS DIST =   -9.96   MEAN SQ X MISS DIST=   8742.   VAR X MISS DIST =   8643.
  AVER Y MISS DIST =   -6.35   MEAN SQ Y MISS DIST=  40536.   VAR Y MISS DIST =  40496.
  AVER R MISS DIST =  179.35   MEAN SQ R MISS DIST=  49278.   VAR R MISS DIST =  17112.
  PERCENT OF HITS = 8.98   NUMBER OF ROUNDS FIRED =  256

RESULTS FOR MANEUVERING PT BOAT WITH SPEED = 30 KNOTS AND SPOTTING MODE 3

  AVER X MISS DIST =   -4.86   MEAN SQ X MISS DIST=   9210.   VAR X MISS DIST =   9187.
  AVER Y MISS DIST =   -8.50   MEAN SQ Y MISS DIST=  56373.   VAR Y MISS DIST =  56301.
  AVER R MISS DIST =  213.78   MEAN SQ R MISS DIST=  65583.   VAR R MISS DIST =  19881.
  PERCENT OF HITS = 5.12   NUMBER OF ROUNDS FIRED =  254

RESULTS FOR MANEUVERING PT BOAT WITH SPEED = 30 KNOTS AND SPOTTING MODE 4

  AVER X MISS DIST =   -9.98   MEAN SQ X MISS DIST=  10339.   VAR X MISS DIST =  10240.
  AVER Y MISS DIST =    -.91   MEAN SQ Y MISS DIST=  40404.   VAR Y MISS DIST =  40403.
  AVER R MISS DIST =  188.64   MEAN SQ R MISS DIST=  50742.   VAR R MISS DIST =  15158.
  PERCENT OF HITS = 5.49   NUMBER OF ROUNDS FIRED =  255
```

Fig. V-8 Results for maneuvering PT boat with speed of 30 knots

```
RESULTS FOR MANEUVERING PT BOAT WITH SPEED = 40 KNOTS AND SPOTTING MODE 1

  AVER X MISS DIST =  -24.44   MEAN SQ X MISS DIST=  11148.   VAR X MISS DIST =  10551.
  AVER Y MISS DIST =   68.82   MEAN SQ Y MISS DIST=  92740.   VAR Y MISS DIST =  88004.
  AVER R MISS DIST =  277.20   MEAN SQ R MISS DIST= 103888.   VAR R MISS DIST =  27048.
  PERCENT OF HITS = 2.39   NUMBER OF ROUNDS FIRED =  209

RESULTS FOR MANEUVERING PT BOAT WITH SPEED = 40 KNOTS AND SPOTTING MODE 2

  AVER X MISS DIST =  -19.75   MEAN SQ X MISS DIST=  12274.   VAR X MISS DIST =  11883.
  AVER Y MISS DIST =  -15.93   MEAN SQ Y MISS DIST=  96963.   VAR Y MISS DIST =  96709.
  AVER R MISS DIST =  278.77   MEAN SQ R MISS DIST= 109237.   VAR R MISS DIST =  31525.
  PERCENT OF HITS = 2.42   NUMBER OF ROUNDS FIRED =  207

RESULTS FOR MANEUVERING PT BOAT WITH SPEED = 40 KNOTS AND SPOTTING MODE 3

  AVER X MISS DIST =   -8.29   MEAN SQ X MISS DIST=  14456.   VAR X MISS DIST =  14387.
  AVER Y MISS DIST =  -14.60   MEAN SQ Y MISS DIST=  98304.   VAR Y MISS DIST =  98091.
  AVER R MISS DIST =  284.58   MEAN SQ R MISS DIST= 112760.   VAR R MISS DIST =  31775.
  PERCENT OF HITS = 3.83   NUMBER OF ROUNDS FIRED =  209

RESULTS FOR MANEUVERING PT BOAT WITH SPEED = 4C KNOTS AND SPOTTING MODE 4

  AVER X MISS DIST =  -26.40   MEAN SQ X MISS DIST=  25658.   VAR X MISS DIST =  24961.
  AVER Y MISS DIST =  -13.72   MEAN SQ Y MISS DIST= 123345.   VAR Y MISS DIST = 123156.
  AVER R MISS DIST =  329.96   MEAN SQ R MISS DIST= 149003.   VAR R MISS DIST =  40128.
  PERCENT OF HITS = 4.31   NUMBER OF ROUNDS FIRED =  209
```

Fig. V-9 Results for maneuvering PT boat with speed of 40 knots

```
RESULTS FOR MANEUVERING PT BOAT WITH SPEED = 50 KNOTS AND SPOTTING MODE 1

  AVER X MISS DIST =   -6.42   MEAN SQ X MISS DIST=  30237.   VAR X MISS DIST =  30195.
  AVER Y MISS DIST =   85.12   MEAN SQ Y MISS DIST= 176404.   VAR Y MISS DIST = 169158.
  AVER R MISS DIST =  386.47   MEAN SQ R MISS DIST= 206640.   VAR R MISS DIST =  57282.
  PERCENT OF HITS = 1.25   NUMBER OF ROUNDS FIRED =  160

RESULTS FOR MANEUVERING PT BOAT WITH SPEED = 50 KNOTS AND SPOTTING MODE 2

  AVER X MISS DIST =    4.50   MEAN SQ X MISS DIST=  17887.   VAR X MISS DIST =  17867.
  AVER Y MISS DIST =  147.35   MEAN SQ Y MISS DIST= 135594.   VAR Y MISS DIST = 113882.
  AVER R MISS DIST =  339.02   MEAN SQ R MISS DIST= 153481.   VAR R MISS DIST =  38548.
  PERCENT OF HITS =  .61   NUMBER OF ROUNDS FIRED =  164

RESULTS FOR MANEUVERING PT BOAT WITH SPEED = 50 KNOTS AND SPOTTING MODE 3

  AVER X MISS DIST =  -21.37   MEAN SQ X MISS DIST=  30793.   VAR X MISS DIST =  30337.
  AVER Y MISS DIST =  -22.29   MEAN SQ Y MISS DIST= 163348.   VAR Y MISS DIST = 162851.
  AVER R MISS DIST =  386.91   MEAN SQ R MISS DIST= 194141.   VAR R MISS DIST =  44444.
  PERCENT OF HITS = 2.47   NUMBER OF ROUNDS FIRED =  162

RESULTS FOR MANEUVERING PT BOAT WITH SPEED = 50 KNOTS AND SPOTTING MODE 4

  AVER X MISS DIST =  -13.51   MEAN SQ X MISS DIST=  28111.   VAR X MISS DIST =  27928.
  AVER Y MISS DIST =  -18.82   MEAN SQ Y MISS DIST= 180755.   VAR Y MISS DIST = 180401.
  AVER R MISS DIST =  401.46   MEAN SQ R MISS DIST= 208866.   VAR R MISS DIST =  47697.
  PERCENT OF HITS =  .59   NUMBER OF ROUNDS FIRED =  170
```

Fig. V-10 Results for maneuvering PT boat with speed of 50 knots

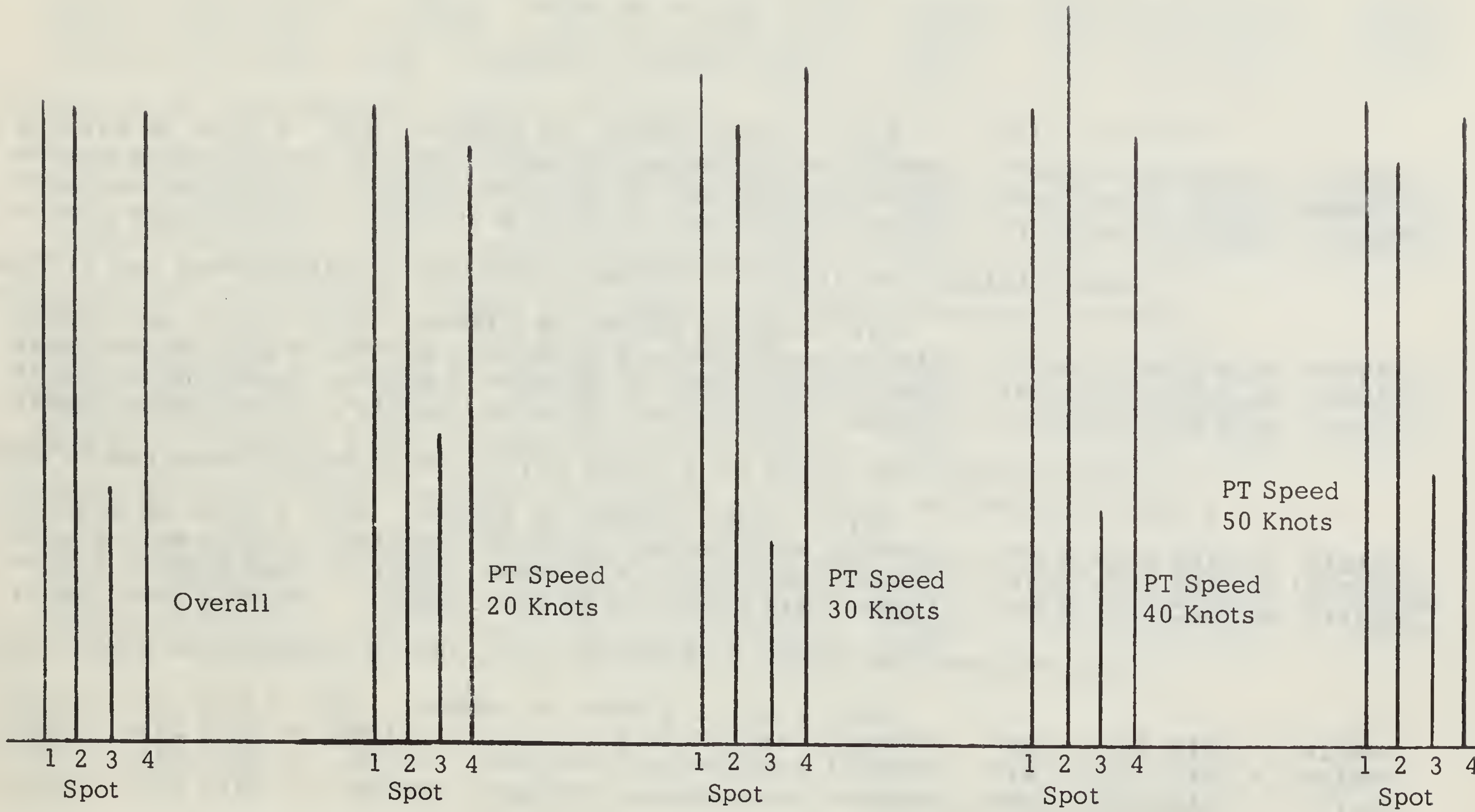

Fig. V-11 Relative results for non-maneuvering runs

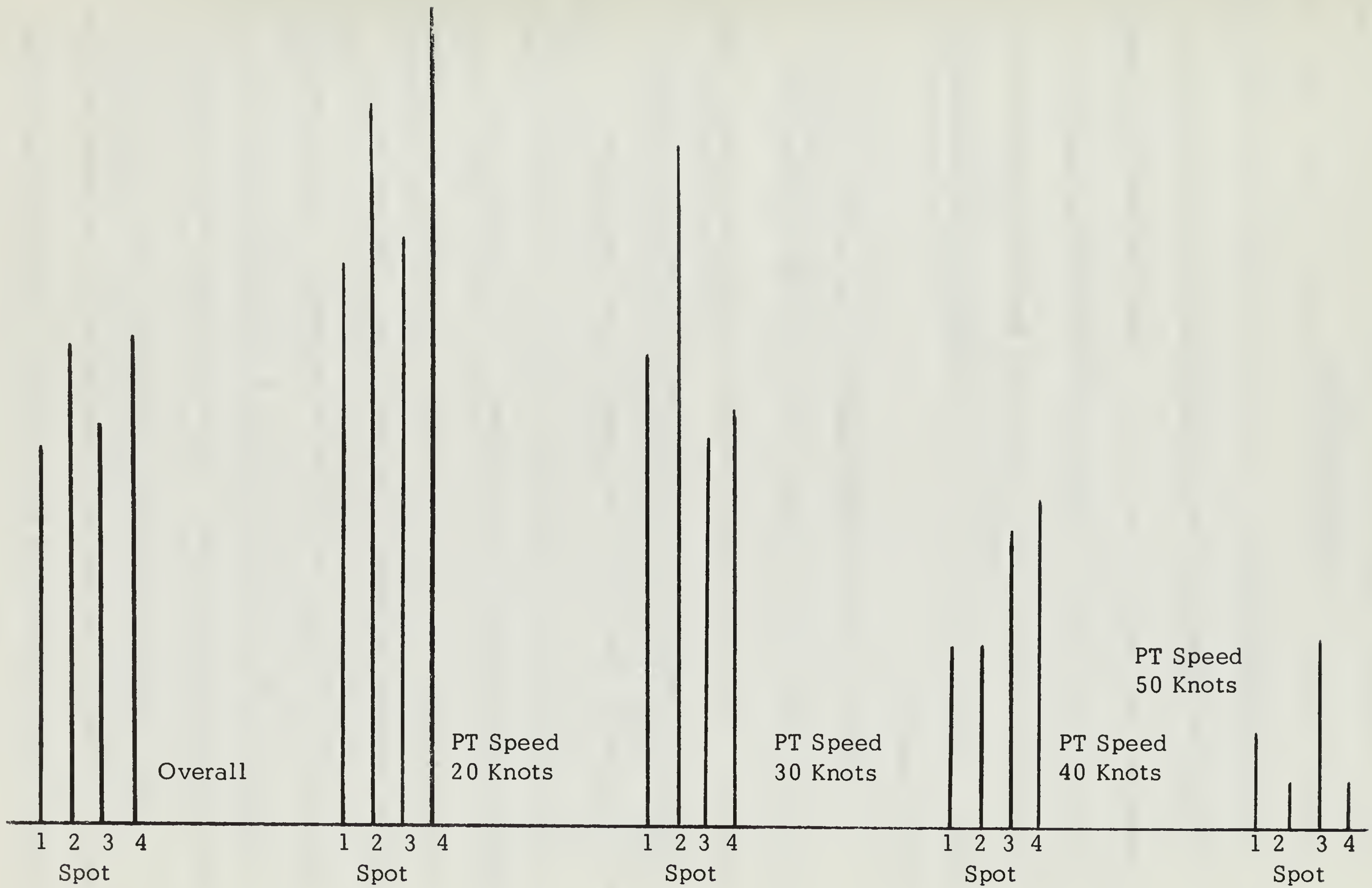

Fig. V-12 Relative results for maneuvering runs

VI. CONCLUSIONS

A. MANEUVER DETECTION

During this simulation it was possible to observe the PT boat make its maneuver, then watch to see if either, or both, the velocity-slaved or position-slaved maneuver detector would detect the maneuver. For the low-speed (twenty and thirty-knot) runs, many maneuvers went undetected. The high-speed runs, forty and fifty-knots, had nearly every maneuver detected.

The position-slaved maneuver detector would normally indicate the maneuver after it was completed and the boat had steadied up on new course. The velocity-slaved maneuver detector would usually start indicating a few seconds after the maneuver commenced and continue for a few seconds after the PT boat steadied up on new course.

The concept behind these adaptive spotting routines has been to combine the best features of two routines, i.e., no spot for a non-maneuvering target and area fire for a maneuvering target. The important thing that has been neglected in the basis of the routines is time of flight (hereafter referred to as TOF) of the projectile. In this simulation, for example, the PT boat would remain on a steady course for fifteen seconds and then change course. The course change would take from four to twelve seconds after which the boat would steady up on new course. The rounds that were being fired during this maneuver would not be splashing for approximately forty seconds. By this time the boat has changed course again. As indicated by the results of Spot 4 for a fifty-knot target, this is not the procedure to follow. It appears, therefore, that firing policy should be a function of TOF of the projectile.

A proposal for an adaptive spotting routine, based on the results of this study, would be:

PT Speed $<$ 30 Knots - Use No Spot

$$\left.\begin{array}{l}\text{PT Speed} > 30 \text{ Knots} \\ \qquad \text{AND} \\ \text{Average time between} \\ \text{maneuvers} < \text{TOF}\end{array}\right\} \text{- Use Random Spot}$$

$$\left.\begin{array}{l}\text{PT Speed} > 30 \text{ Knots} \\ \qquad \text{AND} \\ \text{Average time between} \\ \text{maneuvers} > \text{TOF}\end{array}\right\} \text{- Use No Spot}$$

B. TRACKER PARAMETERS

Another possibility for parameter variation is the number of data points in the LT tracker. Increasing the number of data points would slow the reaction to a maneuver. This might be one form of a spotting procedure. The maneuvers would be removed and no-spot firing could be conducted along the base course. If the number of data points was decreased, the tracker would be more responsive to change in a manner similar to that of the ST tracker. It may be possible to have a "dynamic tracker." When maneuvers are detected the data points are increased to smooth the track, and as the target settles down the data points are again reduced. This would eliminate the need for two trackers.

C. SPOT PATTERNS

Different random-spotting routines should now be tried to see if the hit probabilities for a high-speed, maneuvering target can be increased beyond what it was in this simulation.

Even though the capability of increasing the pattern size as a function of target speed was included in this experiment, it was not used. The pattern was the same size as the rocking-ladder pattern; it just had a different distribution within it. This should definitely be evaluated as well as different pattern shapes. Four different possibilities employing normal and uniform distribution functions were mentioned in Section III. This in no way exhausts the possibilities.

D. GAMING

The human operator on the PT boat will not be as good in spot evaluation as the programmed run due to the low probability of a person being able to exactly duplicate his actions. On the other hand, in order to properly evaluate the spotting system it must be against a run that a human is likely to make. This is where the gaming mode is very useful; a study can be made to see what reaction a human will make to a given situation. These maneuvers can be recorded and used in pre-programmed maneuvers as reactions to given circumstances.

APPENDIX B-1

MAIN PROGRAM BASIC TIMING

Timing is very important in this simulation. The areas of concern (Fig. B-1-1) are: one-second radar data rate, three-second firing rate, time of maneuver, and the variable time remaining to splash. The latter is the most complex and most critical.

The basic one-second signal which controls the radar data rate, firing rate, and maneuver-time indexing, is obtained from the analog computer (Fig. B-1-2). The one-second radar data rate is sensed on Test 1 and acknowledged on Setline 1. The three-second rate is obtained by dividing the one-second rate with a three-bit synchronous counter. The time-to-fire signal is sensed on Test 2 and acknowledged on Setline 2. This signal is prevented while the position segment switching is in progress. This arrangement with the delay flops and setlines prevents a true condition from occurring more than one time for each input. The maneuver elapsed-time counter is incremented in the digital computer each time a data-rate signal is acknowledged.

The time-of-splash timing is accomplished with two different timers, an elapsed-time counter in the digital computer and a sixteen-bit binary counter in the analog computer. This is necessary as there may be as many as fifteen rounds in flight at any given time. The digital computer determines the time of splash by adding the time of flight, at time of firing, to the present time. The time remaining to impact of the first round scheduled to impact is used to initialize the sixteen-bit counter.

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After this round splashes and impact position is acknowledged, the counter is then reinitialized for the next round by subtracting the present elapsed time from the elapsed time of next impact.

For an example of the splash timing, (Fig. B-1-3) consider four rounds being fired three seconds apart starting at time T1. Times T5, T6, T7, and T8 are determined by adding the respective times of flight to T1, T2, T3 and T4. The counter is initialized with the time of flight for round 1 at time T1. Round 1 splashes at time T5. The splash is acknowledged at time t1. The counter is reinitialized at this time with tr2 which is T6 minus t1. Round 2 splashes at time T6 and the splash is acknowledged at time t2. The counter is reinitialized at this time with tr3. This is carried on until round 4 lands.

CLOCKTIMER

CLOCKTIMER is the digital elapsed-time counter. It is initialized at the start of the run and incremented automatically sixty times per second to give timing accuracy to 1/60 of a second.

SUBROUTINE TIMER

SUBROUTINE TIMER sets the initial conditions on a sixteen-bit binary counter. The value of the initial condition is equal to full count minus time remaining to splash. After the initial condition is set, the counter is turned on as a binary up counter. When the counter is filled, the output carry (Fig. B-1-4) is used to indicate a splash flag, disable the counter, and hold the impact position.

The counter is initialized with the use of setlines to the input of NAND gates. After all of the bits have been interrogated a master set pulse is fed into the other input to the NAND gate. If the setline has a true on it when the pulse arrives the particular bit will be set, if not it will not be. The inhibit signal is now removed, allowing the one-thousand-cycle signal to trigger the counter until it is filled. This gives timing accuracy to one thousandth of a second.

To determine if a bit is to be initialized the decimal to binary algorithym (Fig. B-1-5) is used. The least significant bit is checked first. The number is divided by two; if it is an odd number the bit is set, if not it isn't. The interrogation is now incremented to the next bit and repeated until all sixteen bits have been checked.

SPLASHES

The fine segment position is continuously fed into a pair of Track and Holds (Fig. B-1-6). They hold the last relative position until a splash occurs. When the splash occurs they are switched into track condition. They then hold this relative position until the next splash occurs. With the actual impact position, the digital computer can now determine miss distance by subtracting the impact position from the stored predicted-impact position.

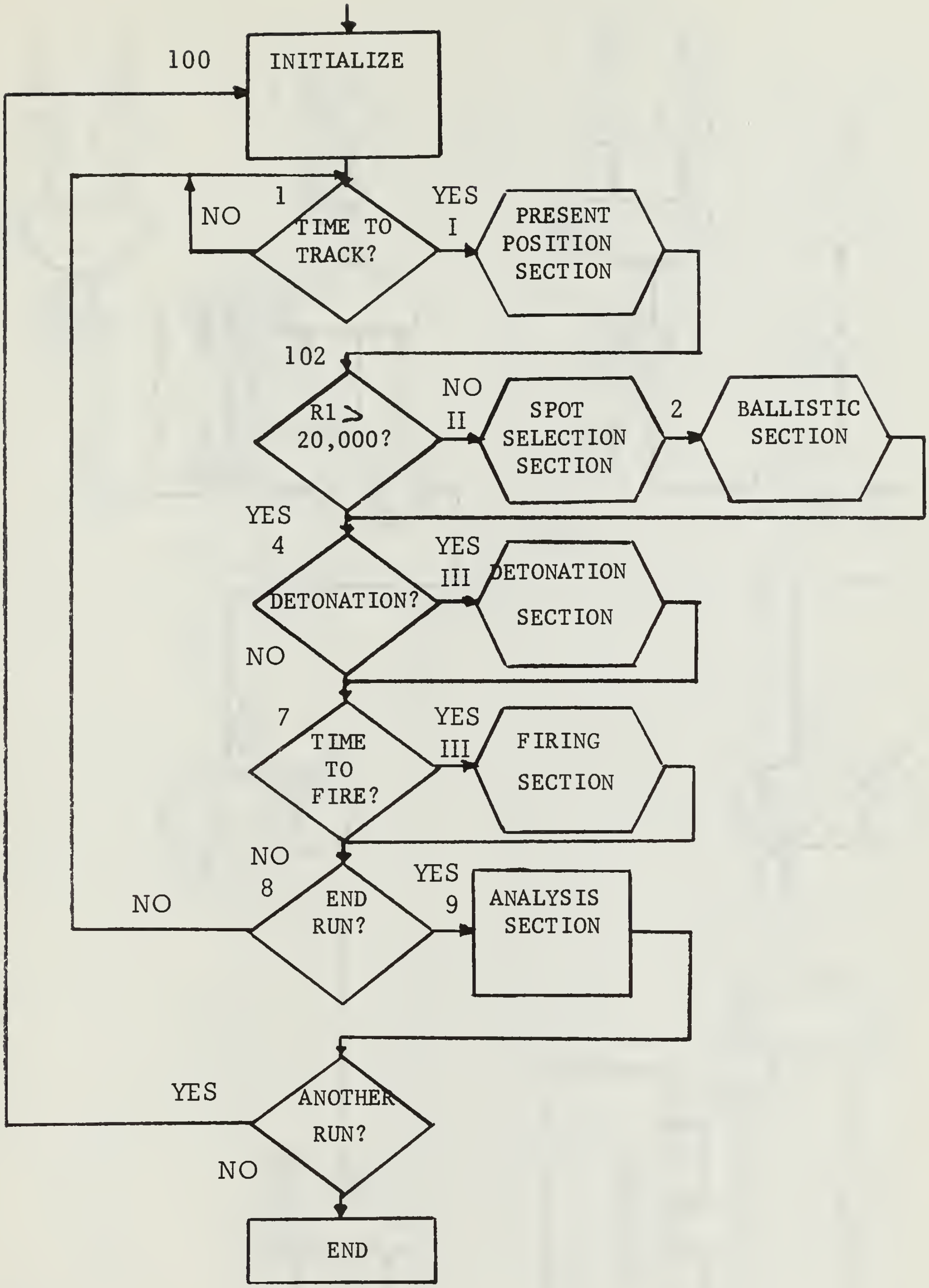


Fig. B-1-1 Flow graph of main program

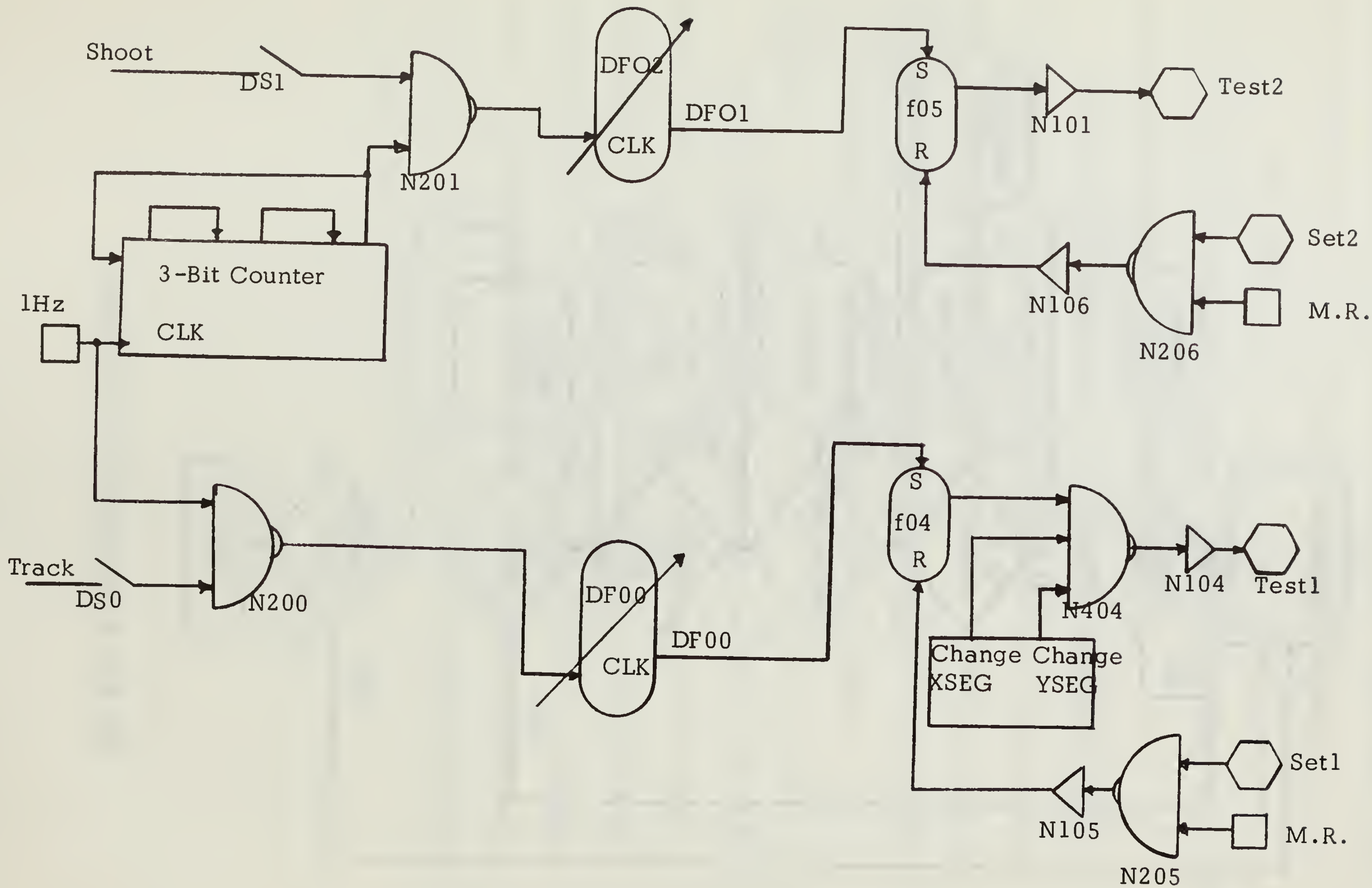


Fig. B-1-2 Analog computer timing circuits

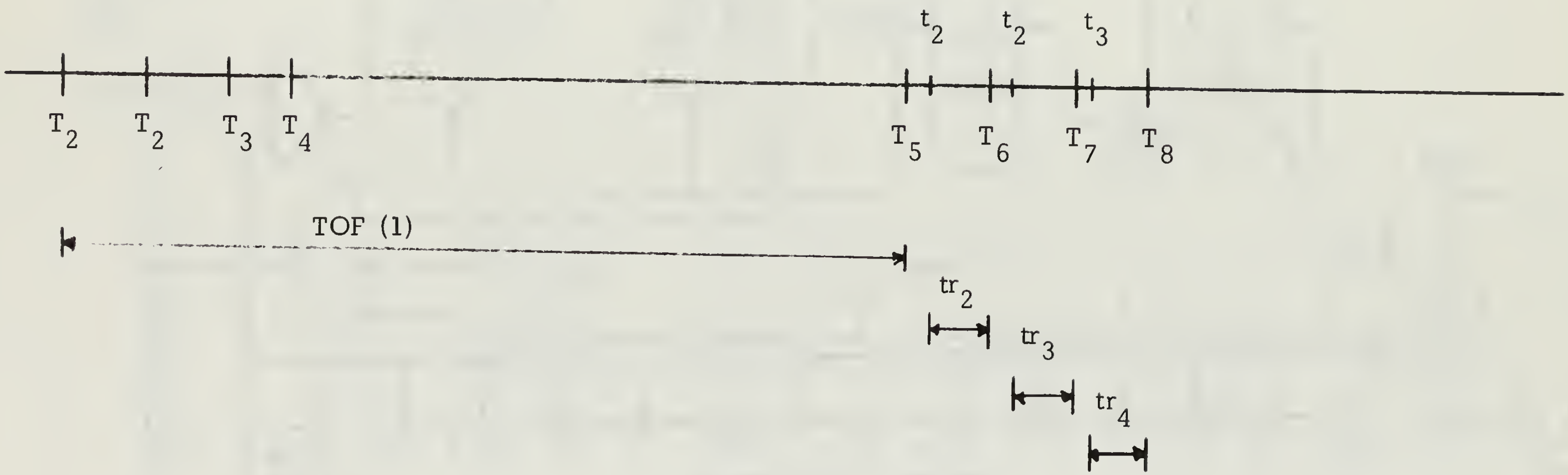


Fig. B-1-3 Splash timing diagram

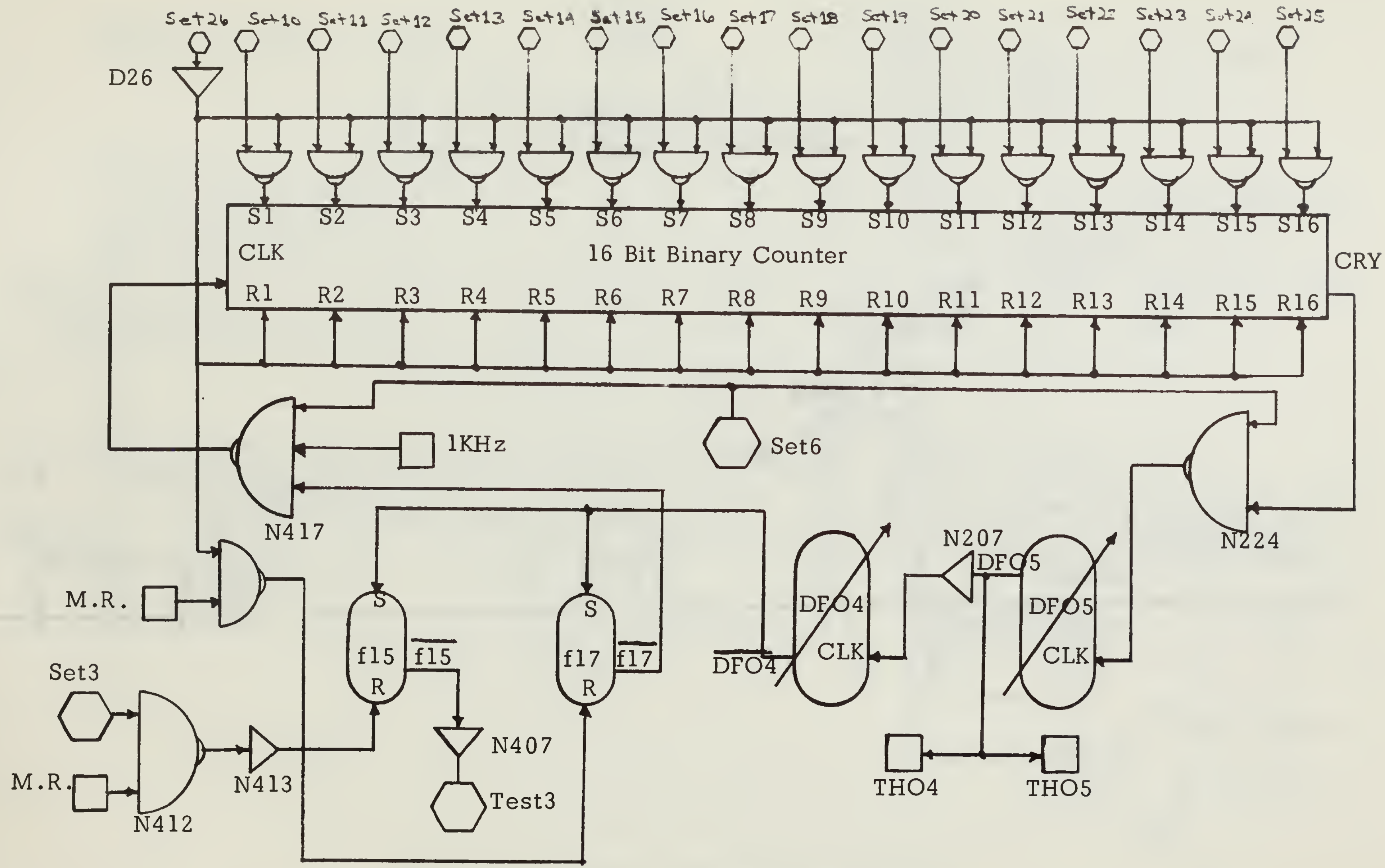


Fig. B-1-4 16-bit counter and splash network

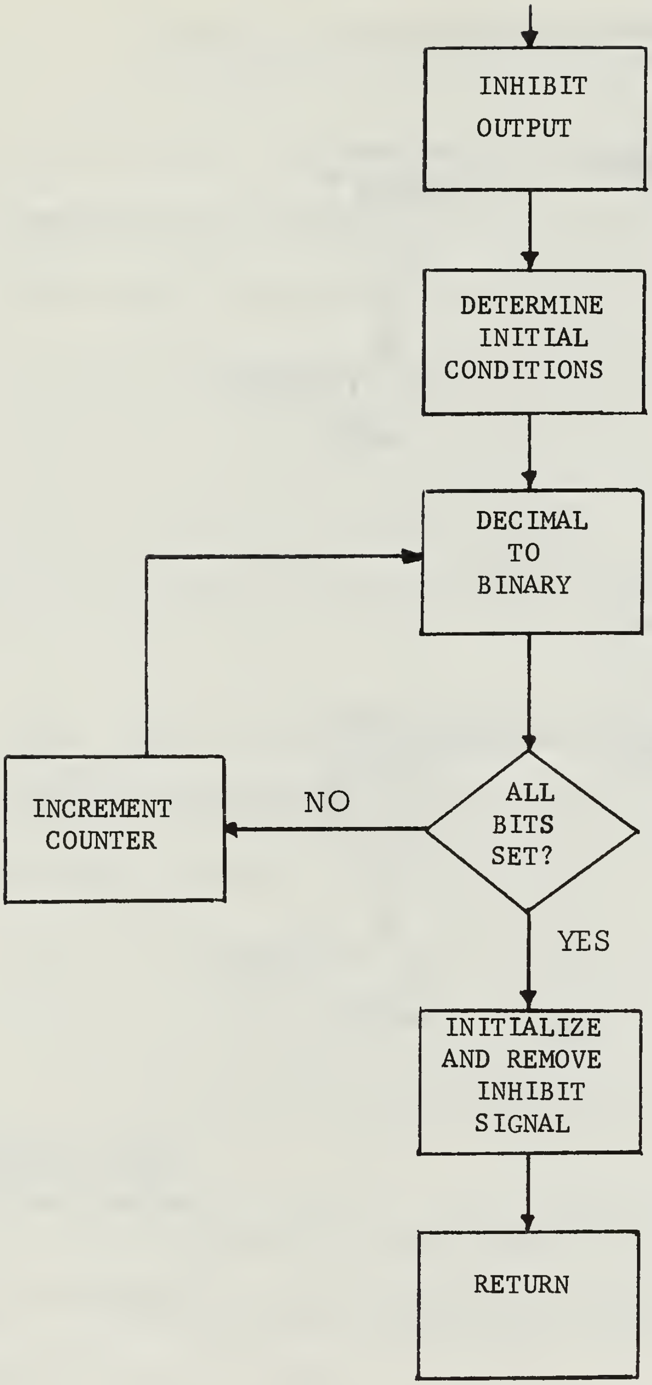


Fig. B-1-5 Flow graph for SUBROUTINE TIMER

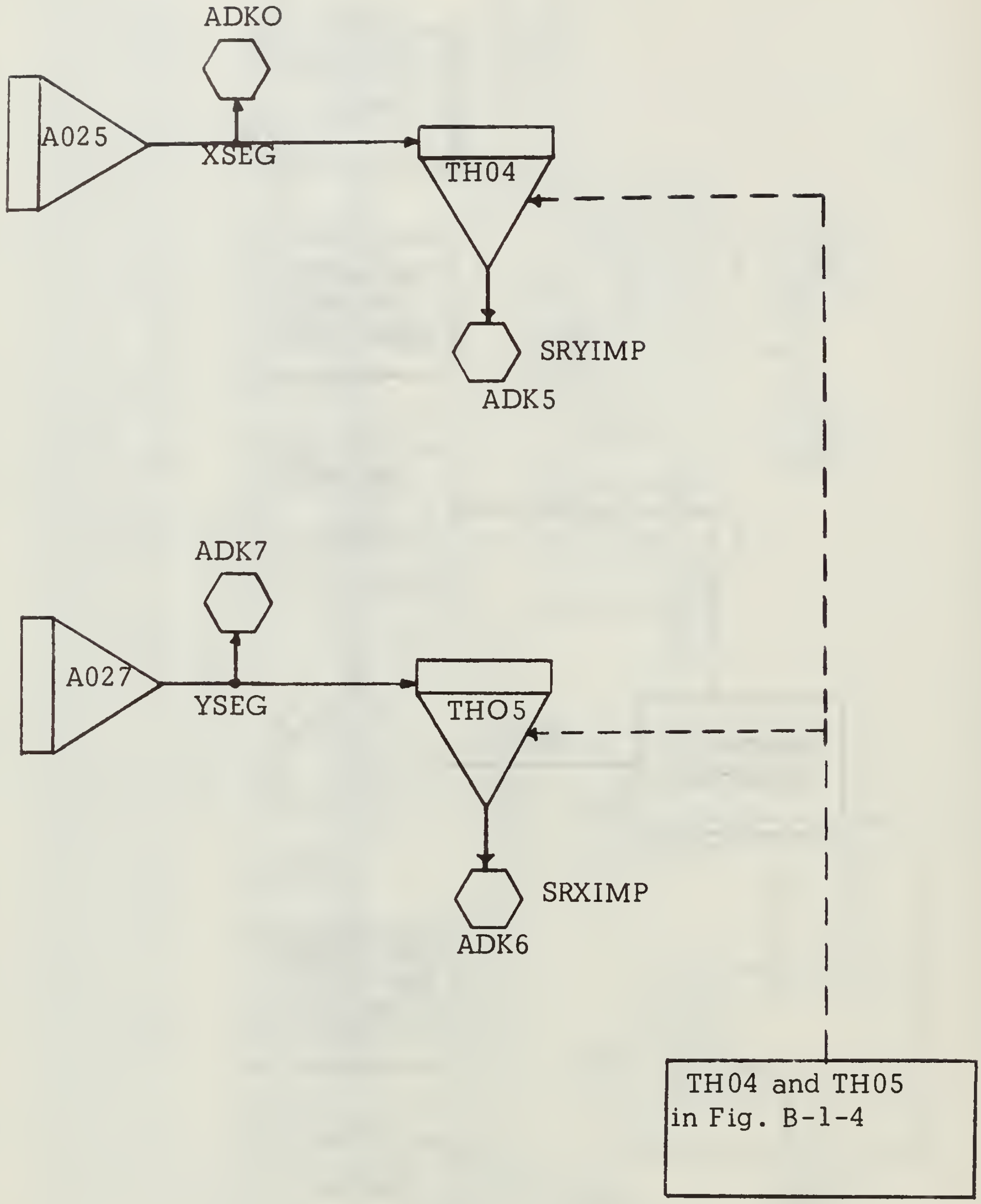


Fig. B-1-6 Impact position storage elements

APPENDIX B-2

PRESENT POSITION SECTION

The present position section (Fig. B-2-1) makes up the radar signal, filters the signal in the tracker and controls the programmed maneuvers.

The radar signal is started with the analog-computer generation of relative position from integration of relative velocities. The actual range is determined by combining the coarse and fine range components from the analog computer in the digital computer. Random noise is added to the actual signal to make up the radar signal in the digital computer.

The radar signal is fed into the tracker. The tracker consists of a Kalman filter for a short-term tracker and a least-squares fit of forty consecutive pieces of data for a long-term tracker. If no maneuver is detected, the ST tracker is used. If a maneuver is detected, position from the ST tracker and velocity from the LT tracker is used. Gain schedules for the ST tracker are computed off-line and stored initially in the tracker.

The maneuvering signal for the PT boat comes from the external PT console in the gaming mode or from SUBROUTINE MANEUVER in the spot-procedure evaluation mode.

RADAR SIGNAL

ANALOG GENERATION

A detailed description of this generation is presented in Ref. 2. In this section the presentation will be brief.

The PT boat (Fig. B-9-1) has an initial velocity in A001 and an initial heading in A005. After the run starts, if there is any difference between ordered velocity and actual velocity as detected in A002, A001 is caused to change. Note that A002 limits the acceleration to some preset value.

The rudder order is fed into A006. This is fed over to A005 with the turning rate, $\dot{\theta}$, being a function of velocity.

The heading, θ, and the velocity, VT are fed into a resolver. The outputs of the resolver are the X and Y components of velocity.

The DD has handset potentiometers (pots) for the value of final velocity. Any difference between initial velocity, on A011 and A015, and final velocity, on P406 and P407, is sensed as a preset limited acceleration in A010 and A016.

The relative position is found by combining two quantities. In order to increase the accuracy of position to an acceptable level, the operating area was divided into segments (Fig. B-2-2). Each segment is four thousand yards square. Each quadrant has twenty-five segments so there is a total of one hundred segments. The segment number is extracted from the full-range integrators A021 and A023. The value of the range within the segment is determined from the segment integrators A025 and A027.

SUBROUTINE RACT

SUBROUTINE RACT (Fig. B-2-3) determines the actual range from the coarse and fine range values. The segment number is determined from the coarse values, XFULL and YFULL. This is done by incrementing the partition boundary until the full-range value is greater than the partition value. This segment number is then checked for proximity to the partition. If the segment value is greater than eighty volts, it is in the lower segment; if not, it is in the upper segment.

For positive values of full-range voltage, actual range is determined by the relation: RAC = 4000(NSF + SEG - 6)

For negative values of full-range voltage, actual range is determined by the relation: RAC = 4000(-NSF - SEG + 6)

This gives RAC as a positive value for every quadrant.

SUBROUTINE RDRNOISE

SUBROUTINE RDRNOISE (Fig. B -2-4) adds gaussian noise to the range and bearing signals. This noise simulates measurement noise that would come from actual radar-signal measurements.

TRACKER

SUBROUTINE TRACKER

This tracker (Fig. B-2-5a and 5b) is very similar to the tracker used in earlier works [1 and 2]. The main difference, as mentioned earlier, is that the velocity is used from the LT tracker for nine measurements after a maneuver is detected.

Gain Schedule

The method of computation for the gain schedule is given in Ref. 1. The only change is in the measurement error covariance matrice, R.

Range $< 15,000$ yards

$$R_1 = \begin{bmatrix} 400 & 0 \\ 0 & 400 \end{bmatrix}$$

Range $\geq 15,000$ yards

$$R_2 = \left(\frac{20,000}{15,000}\right)^2 R_1 = \begin{bmatrix} 711 & 0 \\ 0 & 711 \end{bmatrix}$$

The actual values for the gains are shown in the data section of SUBROUTINE TRACKER.

MANEUVER - A function switch (Fig. B-9-1) on the analog computer is hand switched between the DAC line inputs from SUBROUTINE MANEUVER and the external PT console.

SUBROUTINE MANEUVER

SUBROUTINE MANEUVER (Fig. B-2-6) has rudder and speed orders stored for each run. The subroutine is entered at a predetermined time. The next rudder and speed orders are executed with DAC lines and the time for next entry is determined.

The programmed maneuvers used are at constant speed and execute a zig-zag movement across base course. The turning times are not constant but in each case the PT boat steadies up on new base course for fifteen seconds.

PT CONSOLE

The external PT console (Fig. B-2-7 and 8) has five preset pots for speed and two for rudder orders. Selector switches are used to select the desired order. The different directions of rudder orders are obtained by changing the reference voltage applied to the rudder order pots.

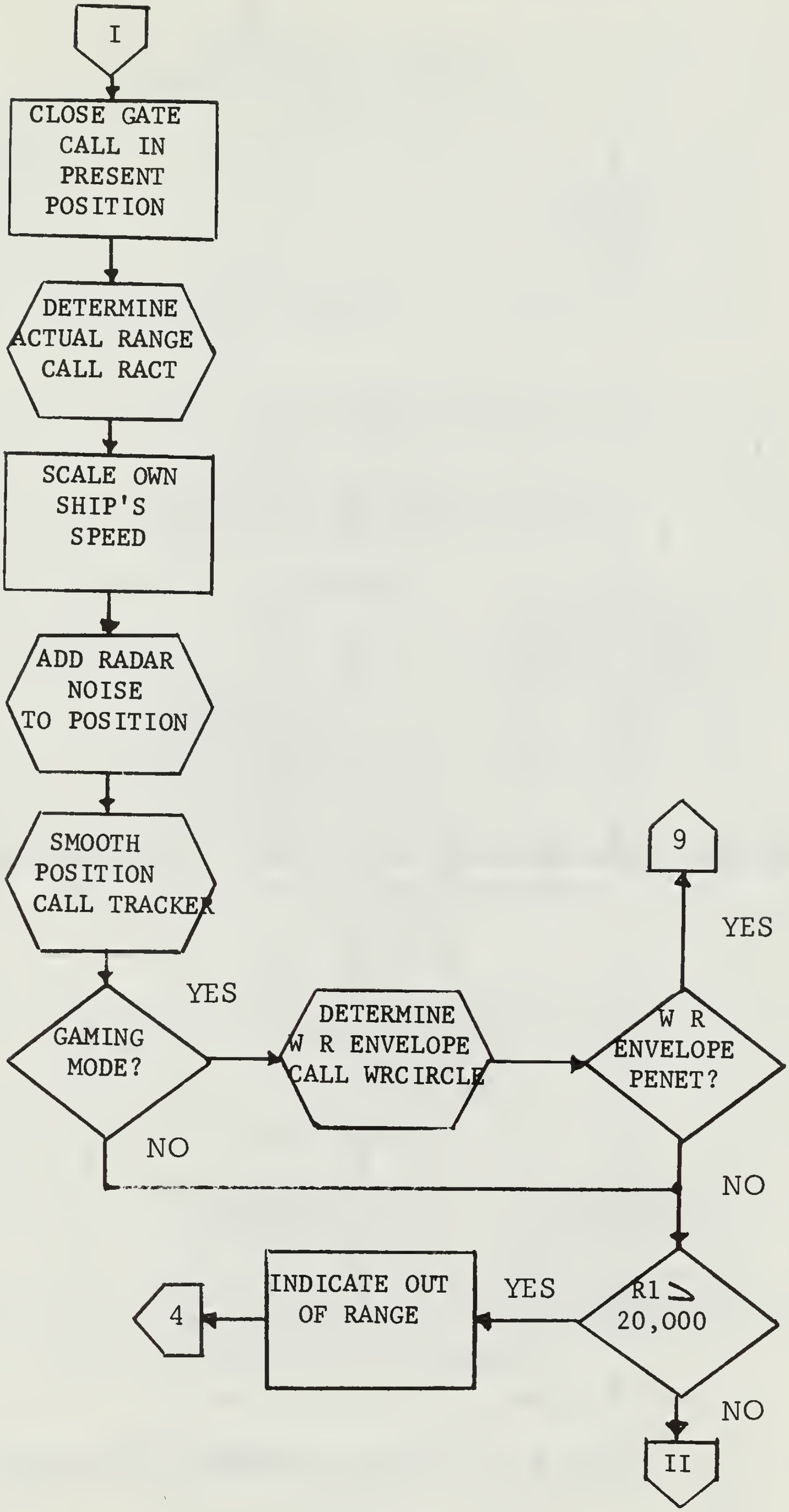


Fig. B-2-1 Flow graph of present-position section

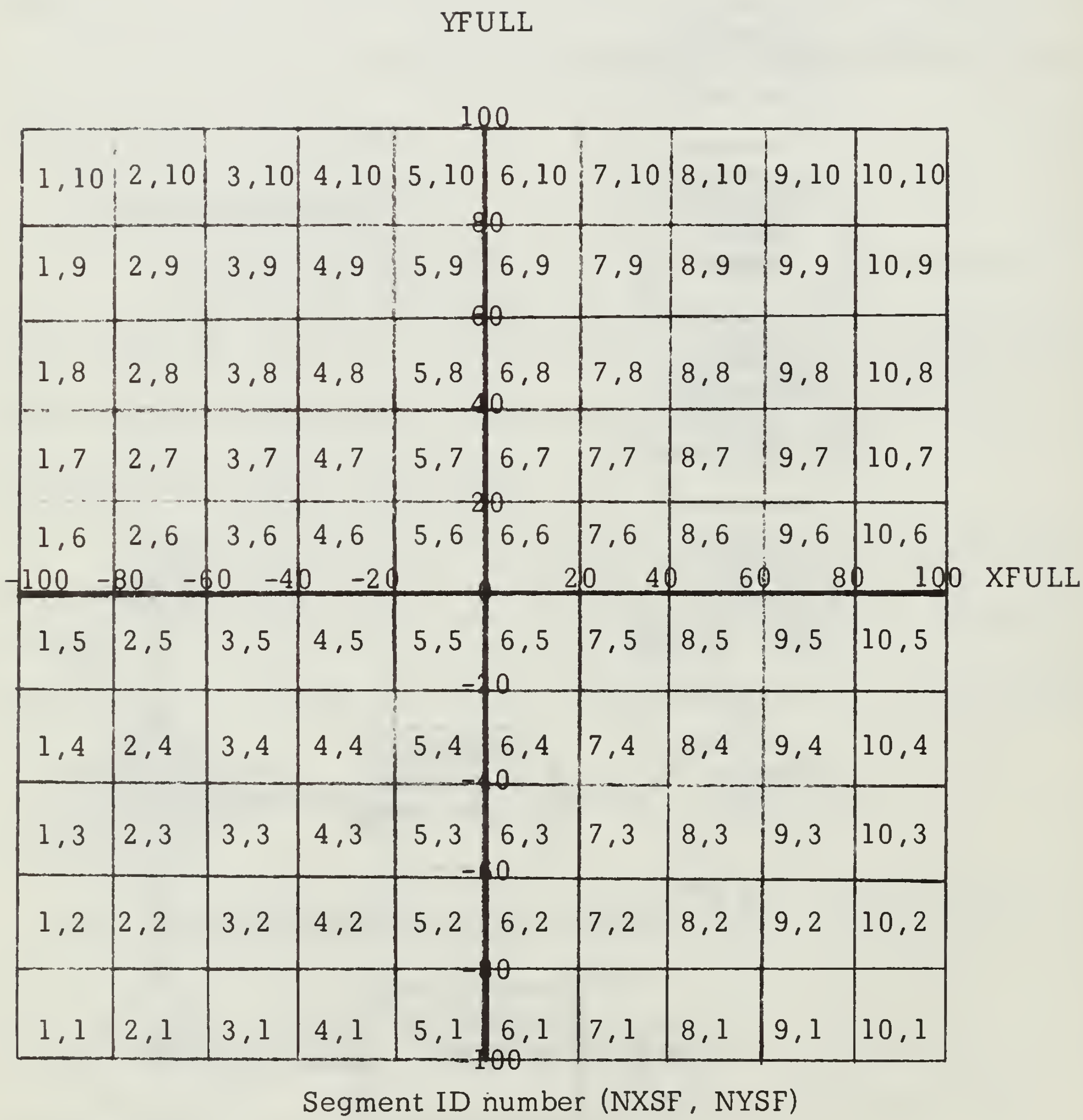


Fig. B-2-2 Position segment identification

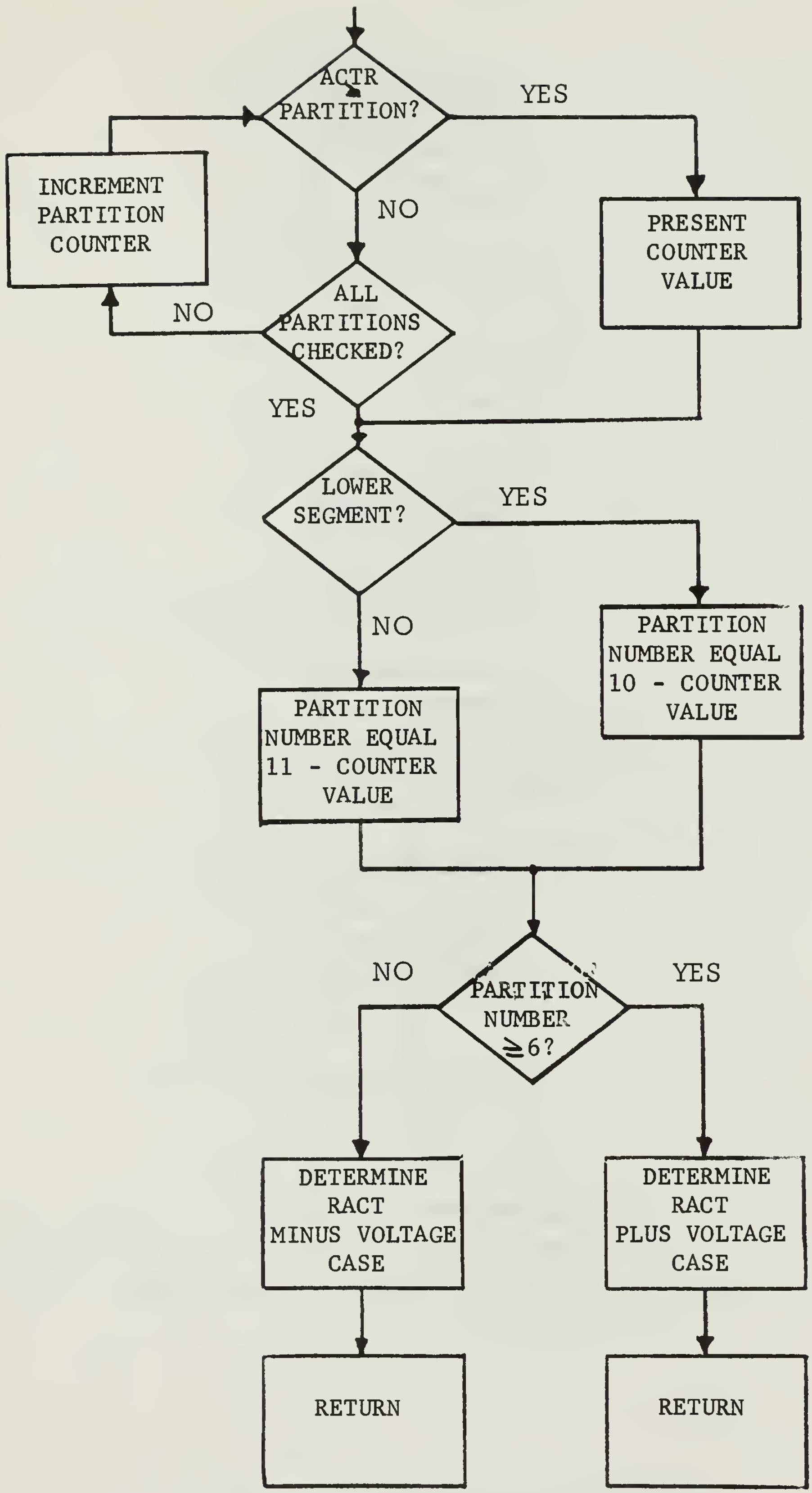


Fig. B-2-3 Flow graph of SUBROUTINE RACT

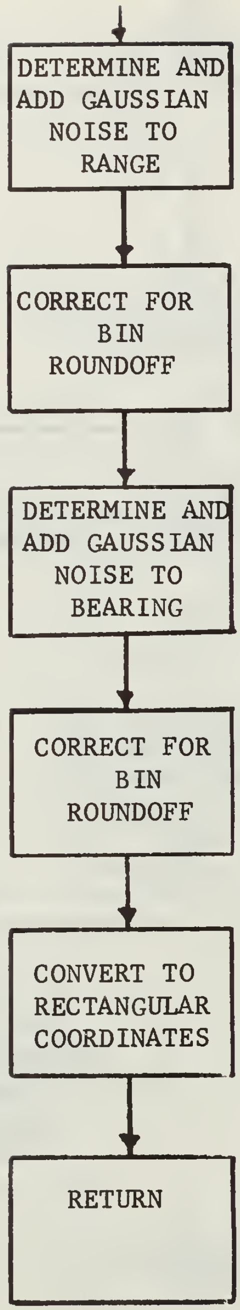


Fig. B-2-4 Flow graph of SUBROUTINE RDRNOISE

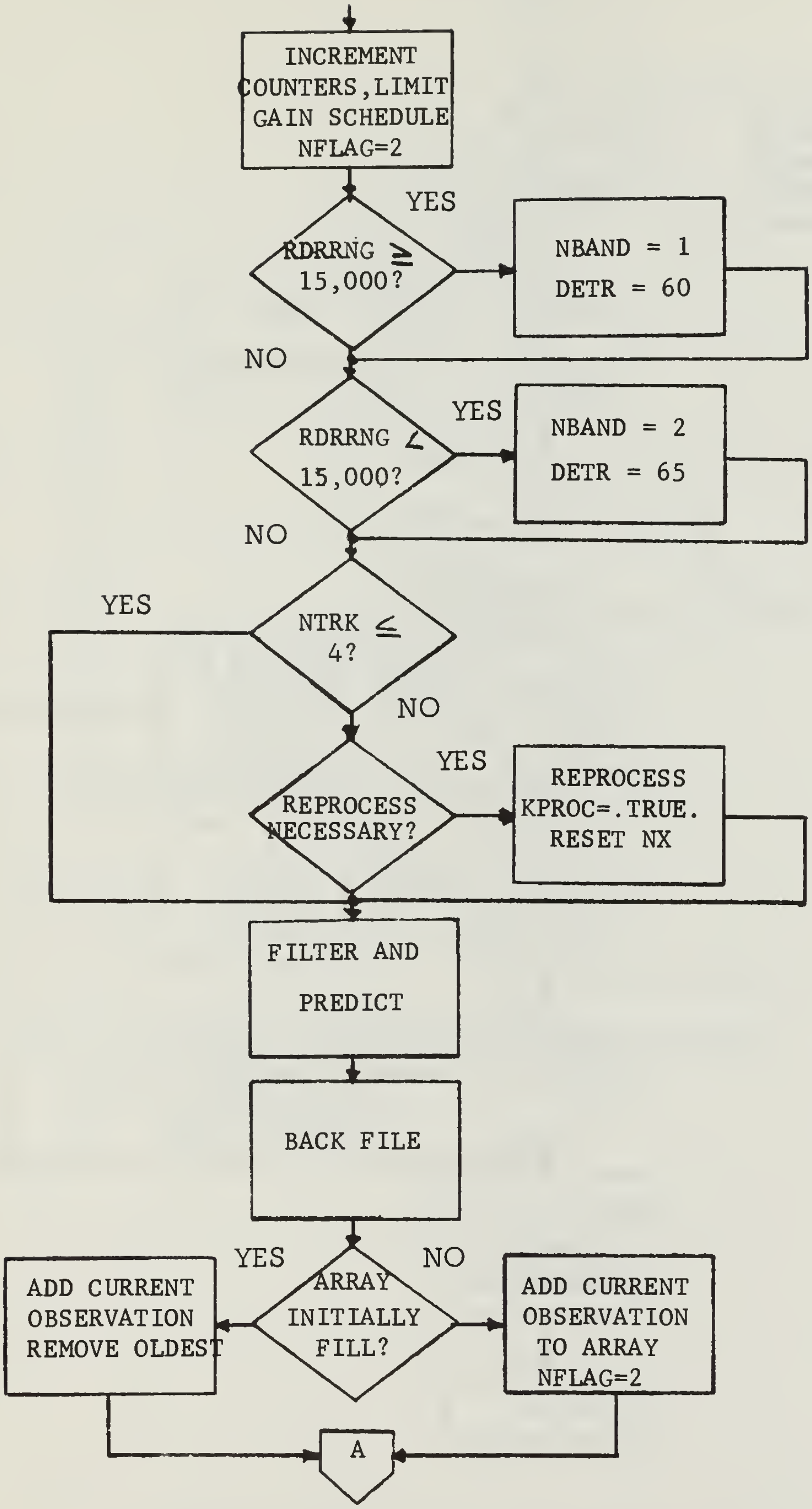


Fig. B-2-5a Flow graph of SUBROUTINE TRACKER

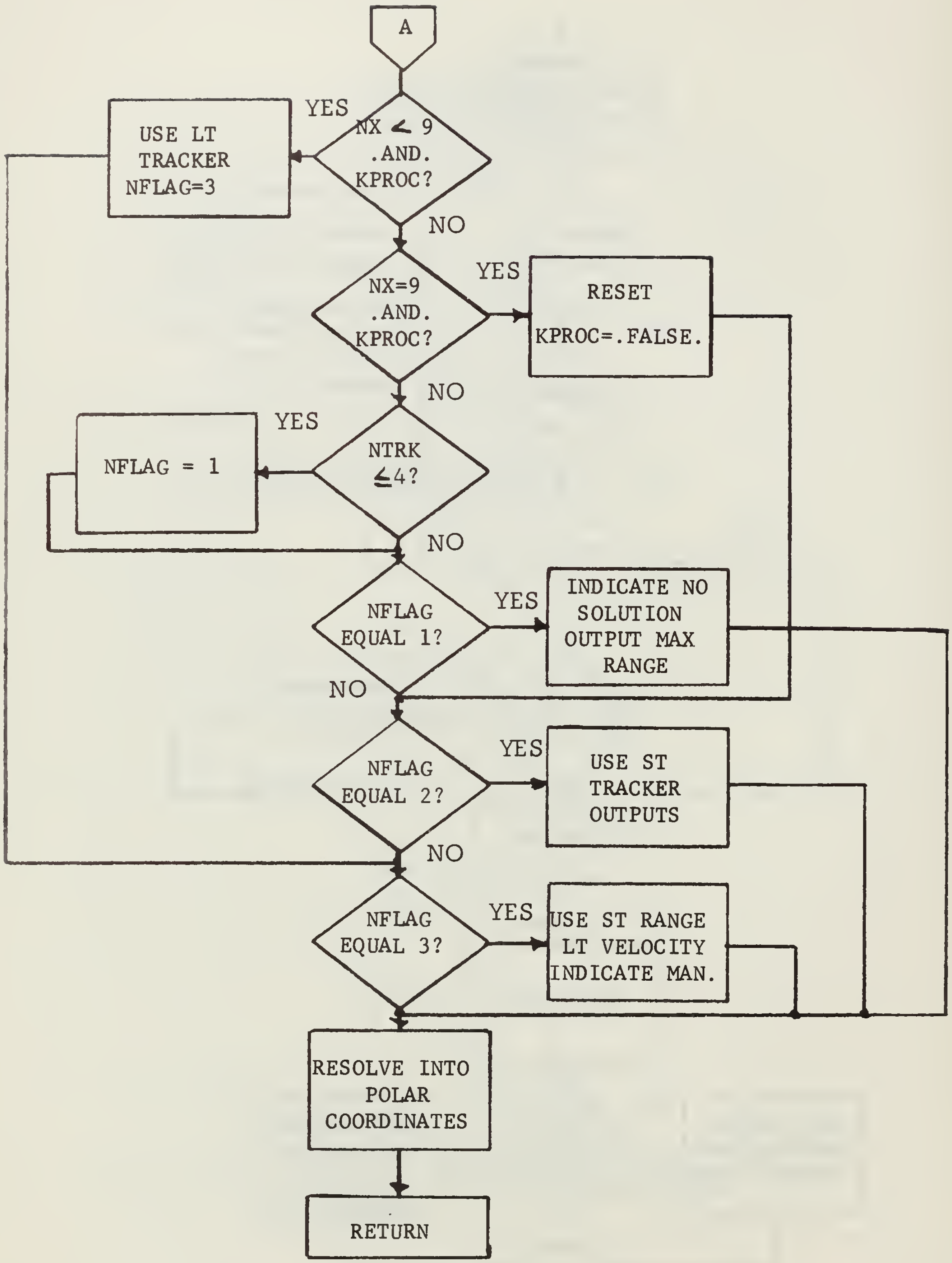


Fig. B-2-5b Flow graph of SUBROUTINE TRACKER

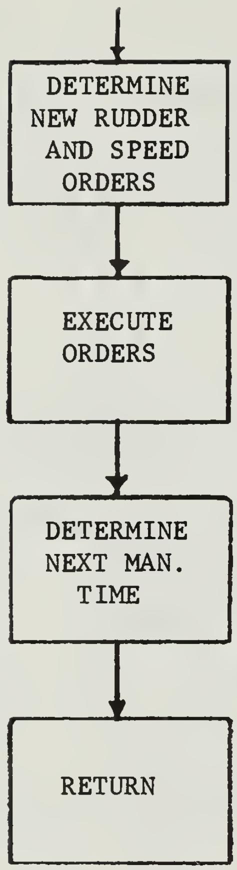


Fig. B-2-6 Flow graph of SUBROUTINE MANEUVER

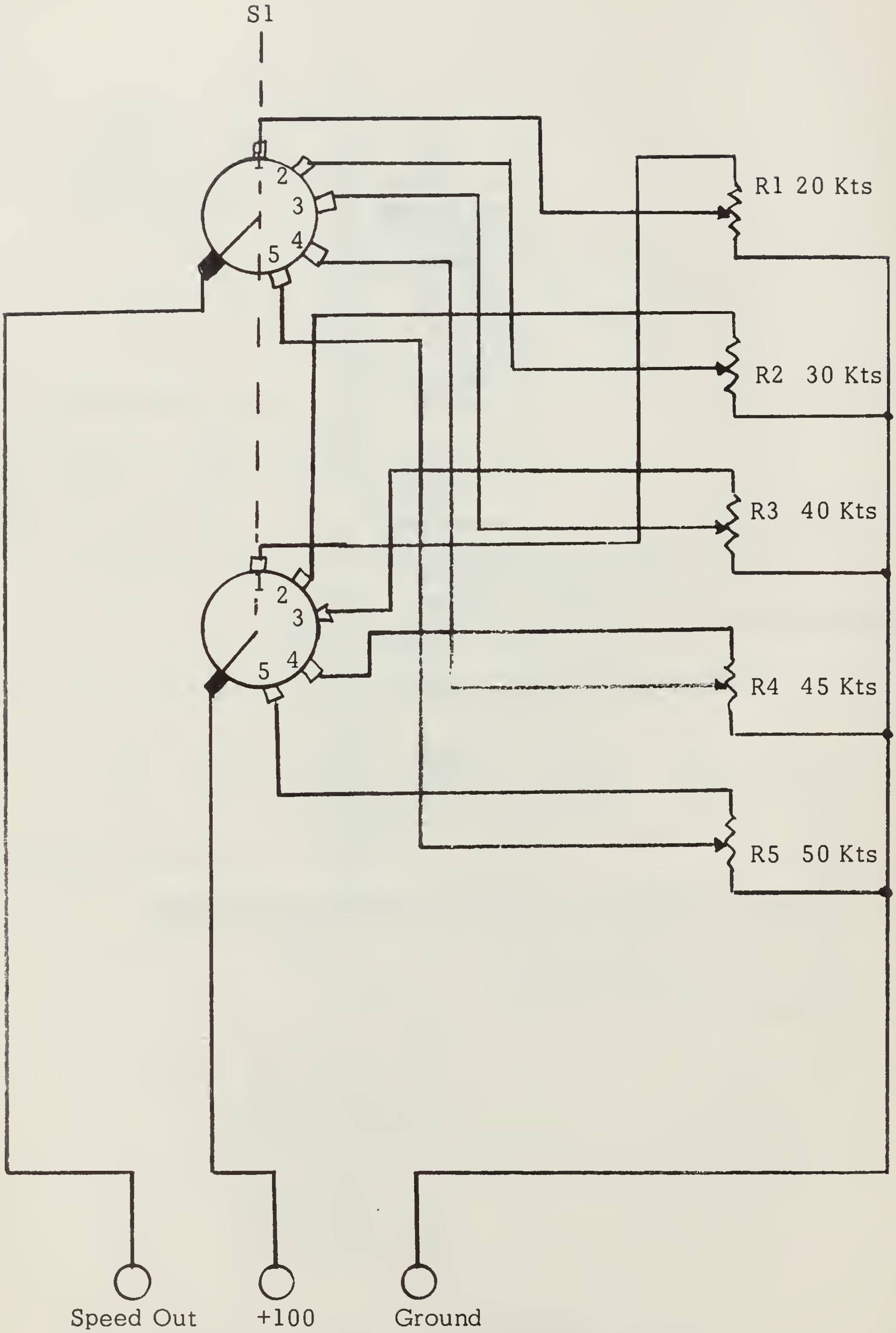


Fig. B-2-7 PT console speed-selector switch

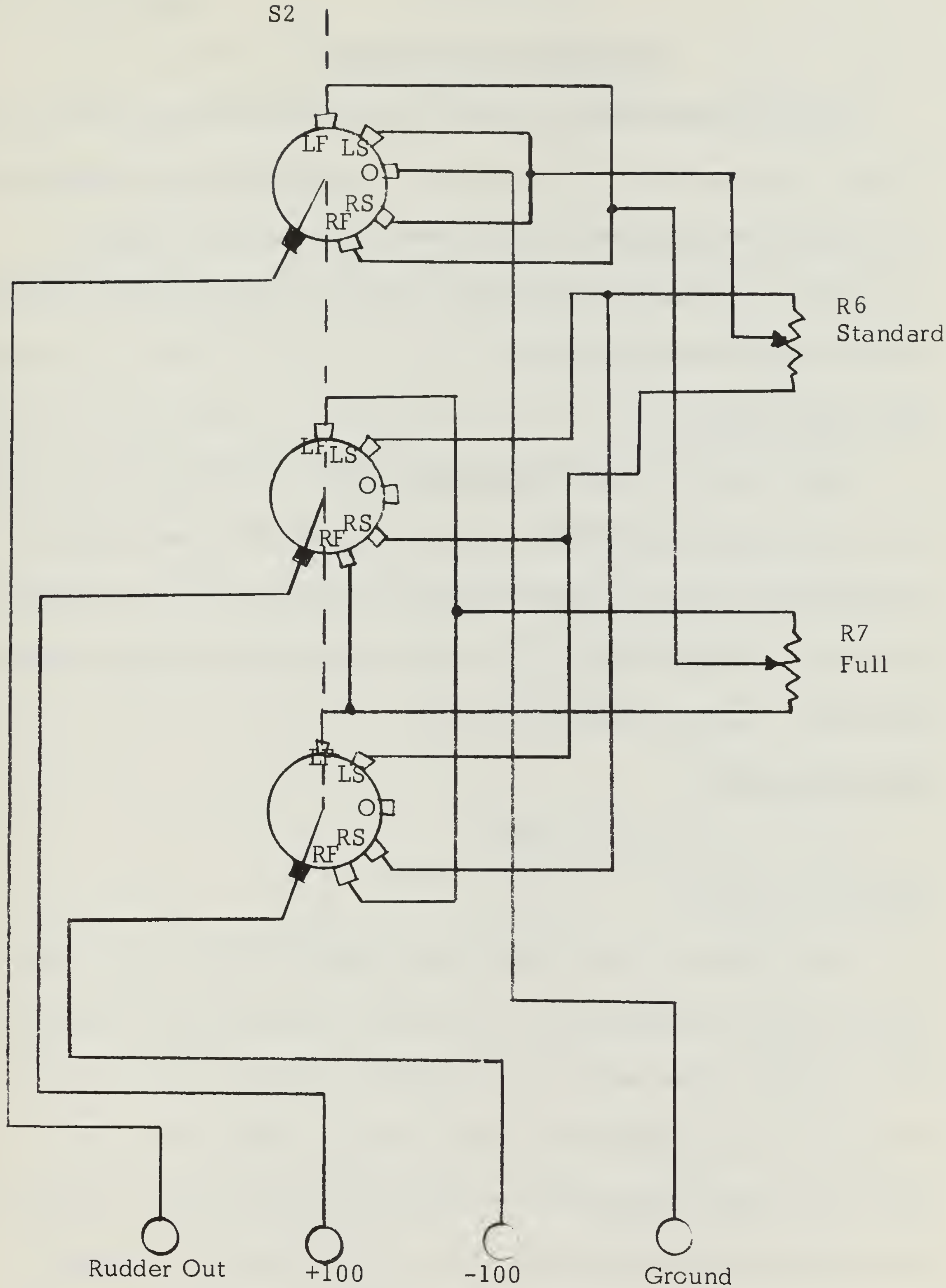


Fig. B-2-8 PT console rudder-order selector switch

APPENDIX B-3

SPOT SELECTION SECTION

There are four different spotting routines stored in the digital program. The particular routine desired is selected by use of testlines from the logic section of the analog computer (Fig. B-3-1). The destroyer skipper chooses the desired routine by setting toggle switches, which in turn set the testlines.

SPOT SELECTION 1

Spot selection 1 uses SUBROUTINE SPOTNORM (Fig. B-3-2). This is a rocking-ladder spot which will give pointed fire in each of nine different quadrants. The spots consist of all nine combinations of left five mils, no bearing spot, right five mils, add one hundred yards, no range spot, and drop one hundred yards.

SPOT SELECTION 2

Spot selection 2 is no spot.

SPOT SELECTION 3

Spot selection 3 uses SUBROUTINE RANDSPT (Fig. B-3-3). This procedure adds a uniform spot in range and a gaussian spot in bearing. The magnitude of the range spot is dependent upon the velocity of the PT boat as is the spread of the bearing gaussian spot. The maximum range spot varies linearly from one hundred yards with zero PT speed to two hundred yards at fifty knots. The standard deviation for bearing spot was varied linearly from five mils at zero PT speed to ten mils at fifty knots. This was done in order to have a larger pattern at higher target speed.

SPOT SELECTION 4

Spot selection 4 uses SUBROUTINE ADPSPOT (Fig. B-3-4). This procedure uses a random spot if a maneuver is detected and no spot for a nonmaneuvering situation.

The maneuver detection is sensed by comparing the velocity output of the ST tracker to the velocity output of the LT tracker. If this difference is greater than one yard per second and of the same sign for two successive tracks, a maneuver is said to be in progress. This scheme has the ability to detect a maneuver when it first begins and continue detecting while it is in progress. The velocity maneuver detection in previous work [2] indicated the maneuver after the target steadied up on new course.

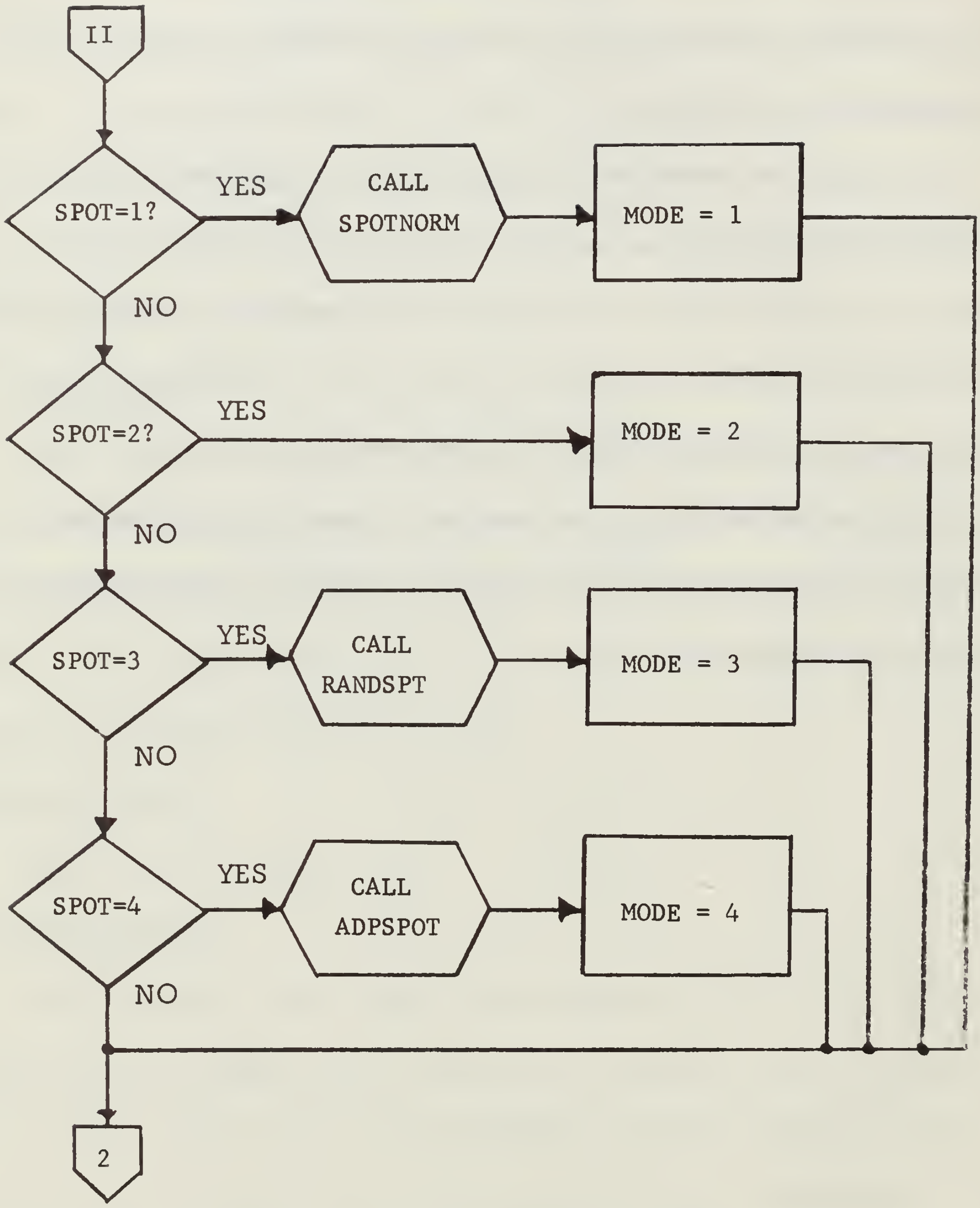


Fig. B-3-1 Flow graph of spot-selection section

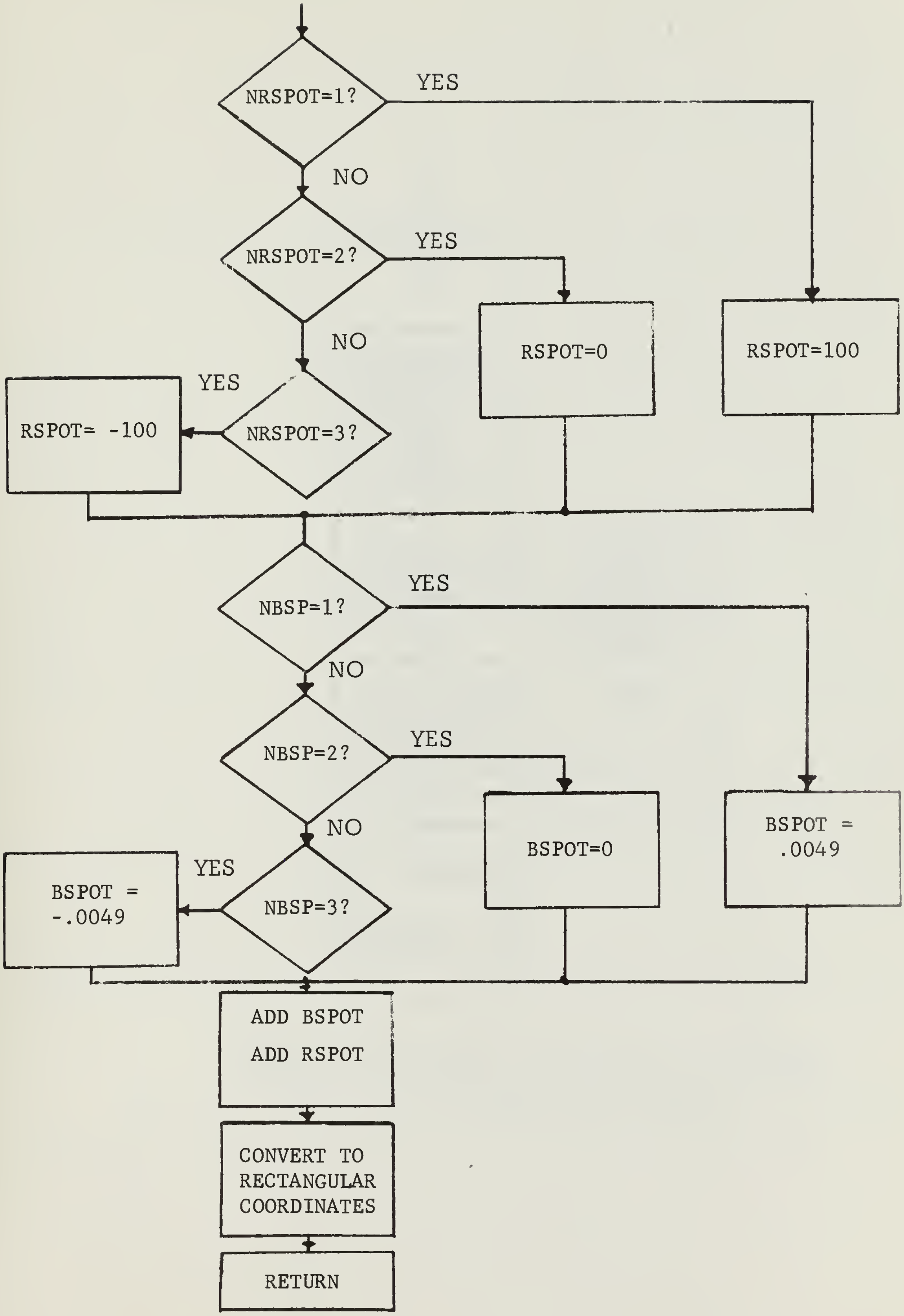


Fig. B-3-2 Flow graph of SUBROUTINE SPOTNORM

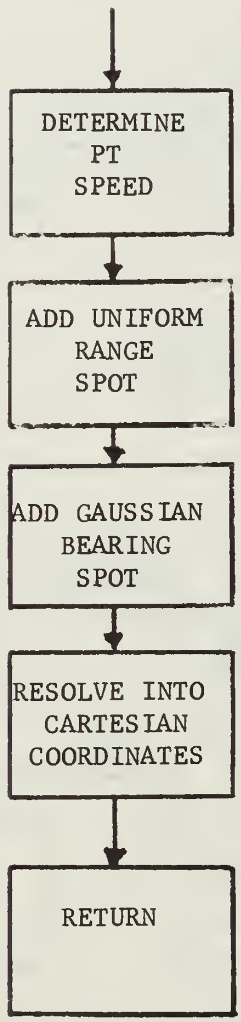


Fig. B-3-3 Flow graph of SUBROUTINE RANDSPT

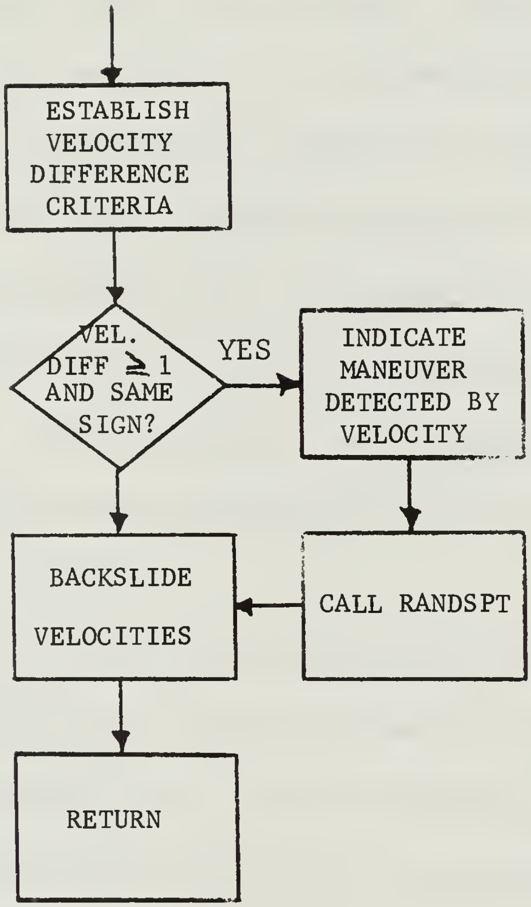


Fig. B-3-4 Flow graph of SUBROUTINE ADPSPOT

APPENDIX B-4

BALLISTIC SECTION

The ballistic section (Fig. B-4-1) determines the projectile time of flight and adds gun dispersion to the predicted impact point.

Time of flight is determined by table lookup. The table is divided into eight segments. There are fourth-degree pelynomial curve-fit coefficients for each segment. An initializing value of predicted position, R2, is determined. This gives a value of time of flight, T2. The table lookup is now repeated to get another value of T2. This will give another predicted impact position, R3. R3 is compared with R2. If they are within a specified amount, RL, the value for T2 is correct; if not, R2 is adjusted and another value is computed for T2. This is repeated until two successive values of predicted impact position are within one yard of each other.

After time of flight and predicted impact position have been determined, gun dispersion is added to the predicted impact position. This is accomplished by looking up the variance in a table of polynomial curve-fit coefficients. The variance is then used in subroutine GAUSS to get a normally distributed value to add for dispersion.

SUBROUTINE PLOOK

SUBROUTINE PLOOK (Fig. B-4-2) accomplishes the table lookup for time-of-flight and dispersion-variance coefficients. Plook first determines which segment R3 is in. This is done by comparing it to the different segment partitions, starting with the highest value. When the proper segment is found the difference between R3 and the partition is calculated. This value, R, is used with the coefficients to determine T2 or gun dispersion variance.

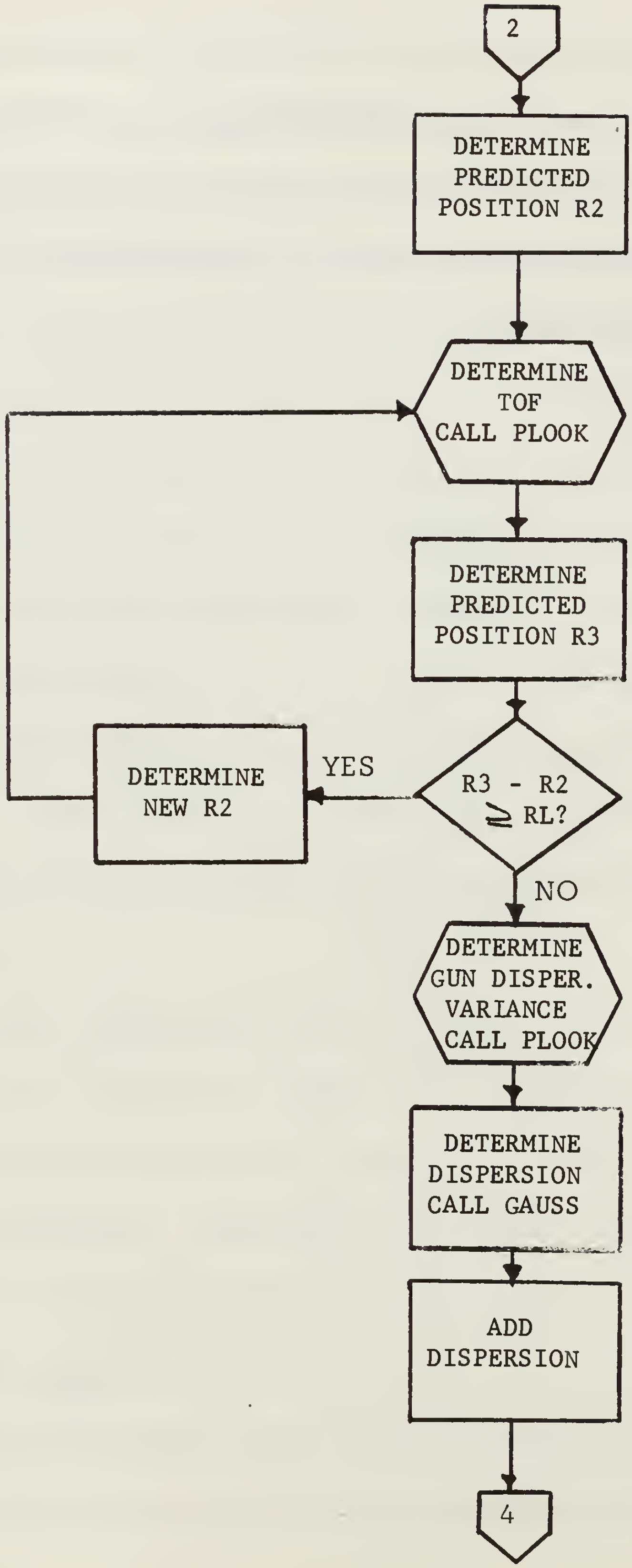


Fig. B-4-1 Flow graph of ballistic section

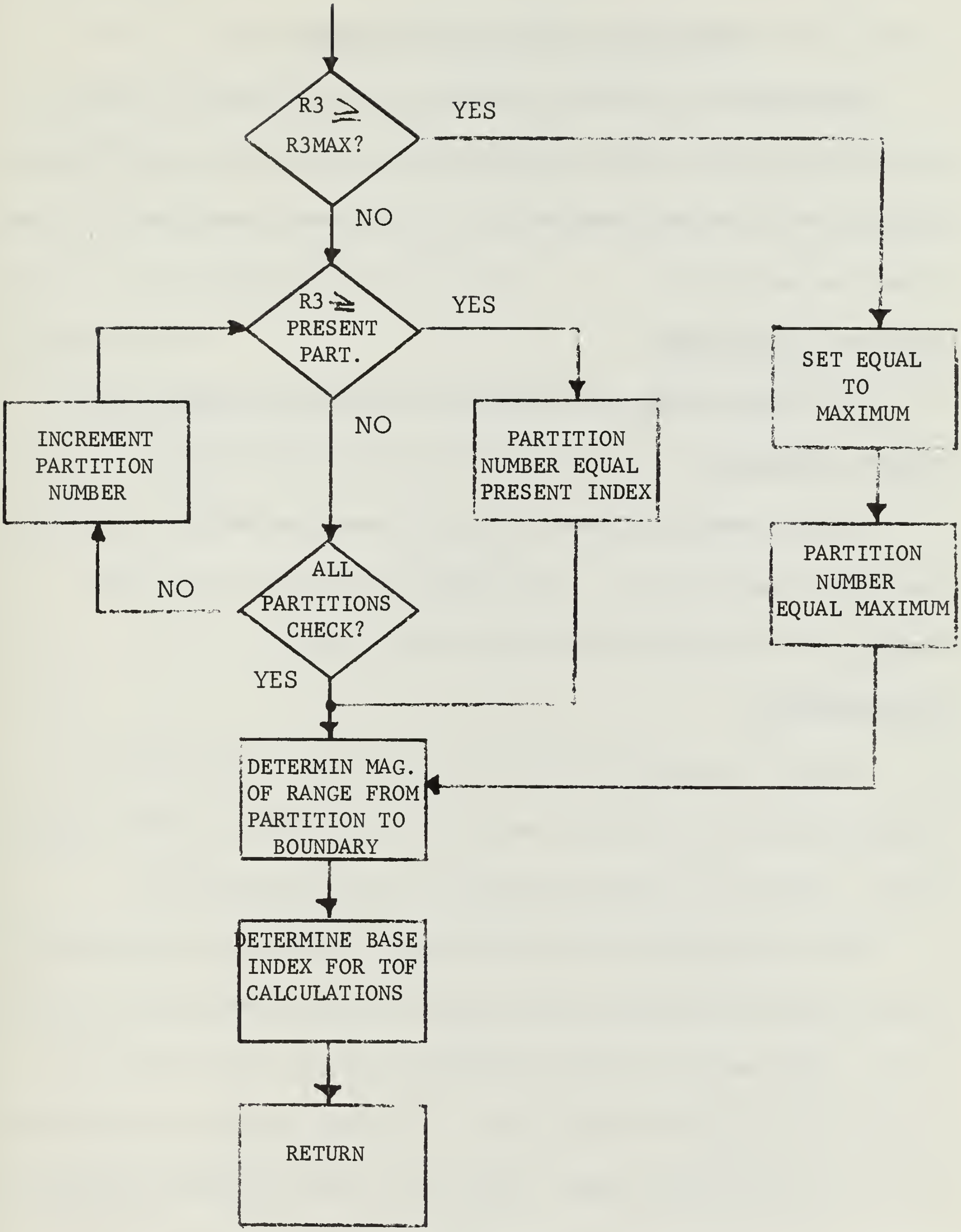


Fig. B-4-2 Flow graph of SUBROUTINE PLOOK

APPENDIX B-5

PROJECTILE DETONATION SECTION

The projectile detonation section (Fig. B-5-1) brings in impact position, determines miss distances, displays and stores miss distances, reinitializes the splash timer, and, if in the gaming mode, ends the game if the round was a hit.

ACKNOWLEDGE SPLASH

The splash occurrance flag (Fig. B-1-4) is reset with testline 3.

IMPACT POSITION

Impact position is stored in a pair of track and holds, as was mentioned in Appendix B-1. The voltage is brought into the digital computer on an A/D line and converted into yardage.

MISS DISTANCE

In order to calculate the miss distance it is first necessary to reconstruct the actual relative position from the course and fine segment values. How this is accomplished was shown in Appendix B-2.

The miss distance is now calculated by subtracting the predicted impact point (with dispersion added) from the actual position at time of impact. This has to be checked for the possibility (Fig. B-5-2) of a segment switch occurring after splash. An actual splash S1 could show up as S1' giving a large error. This check is made with the assumption that no miss distance could be greater than three thousand yards. The miss distance is now stored for analysis purposes and hard limited to two hundred yards for display purposes.

SPLASH TIMER

The next splash time is extracted from the projectile splash array. The time remaining to splash is computed and used to initialize the 16-bit counter as explained in Appendix B-1. If there are no rounds remaining in flight, the splash timer is reset to zero and inhibited, and the first round condition flag is then set.

GAMING MODE

If the program is in the gaming mode (i.e., Sense Switch 4 is true) the polar miss distance is checked for hit criteria. If a hit, the run is ended and the destroyer wins; if not, the game continues.

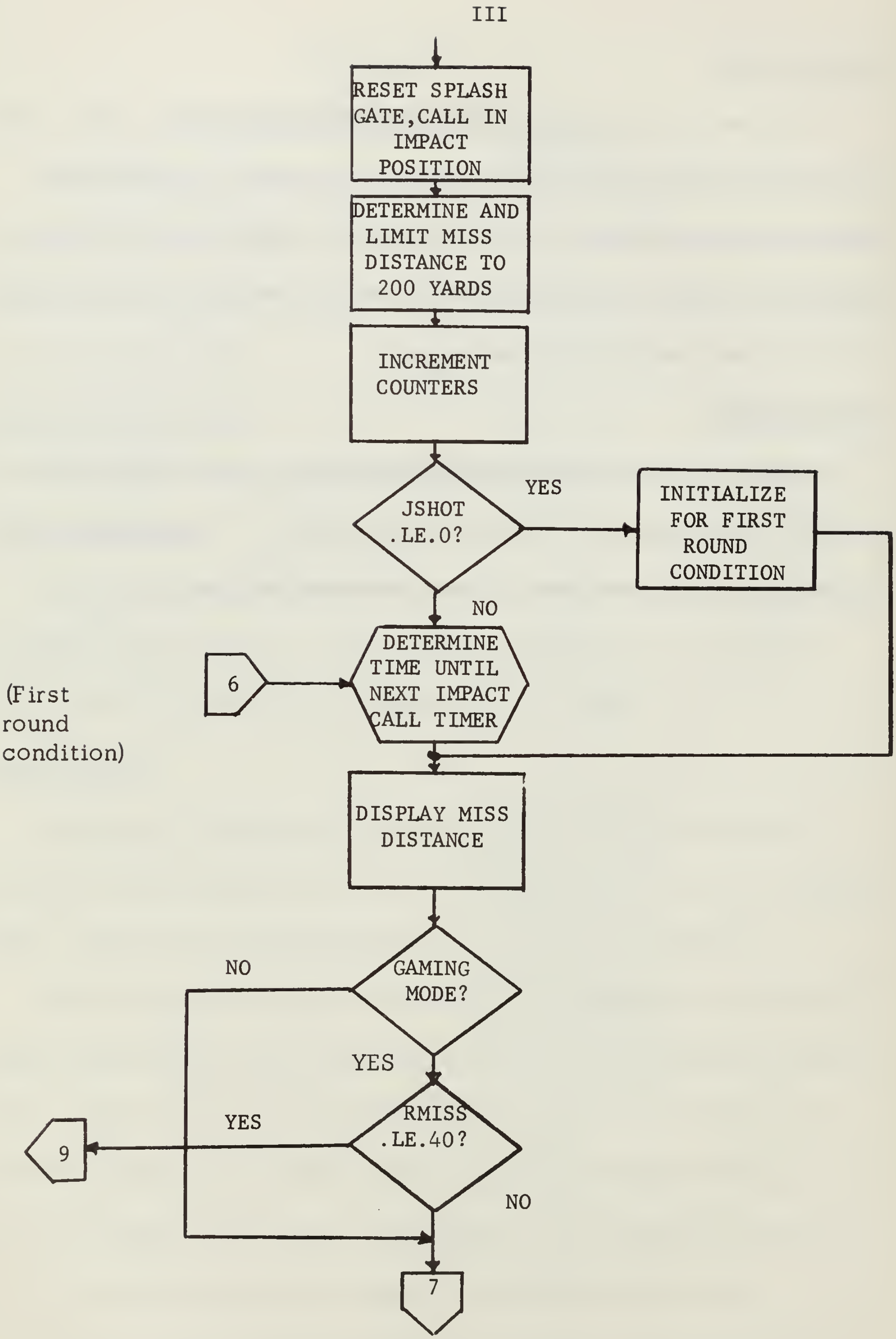
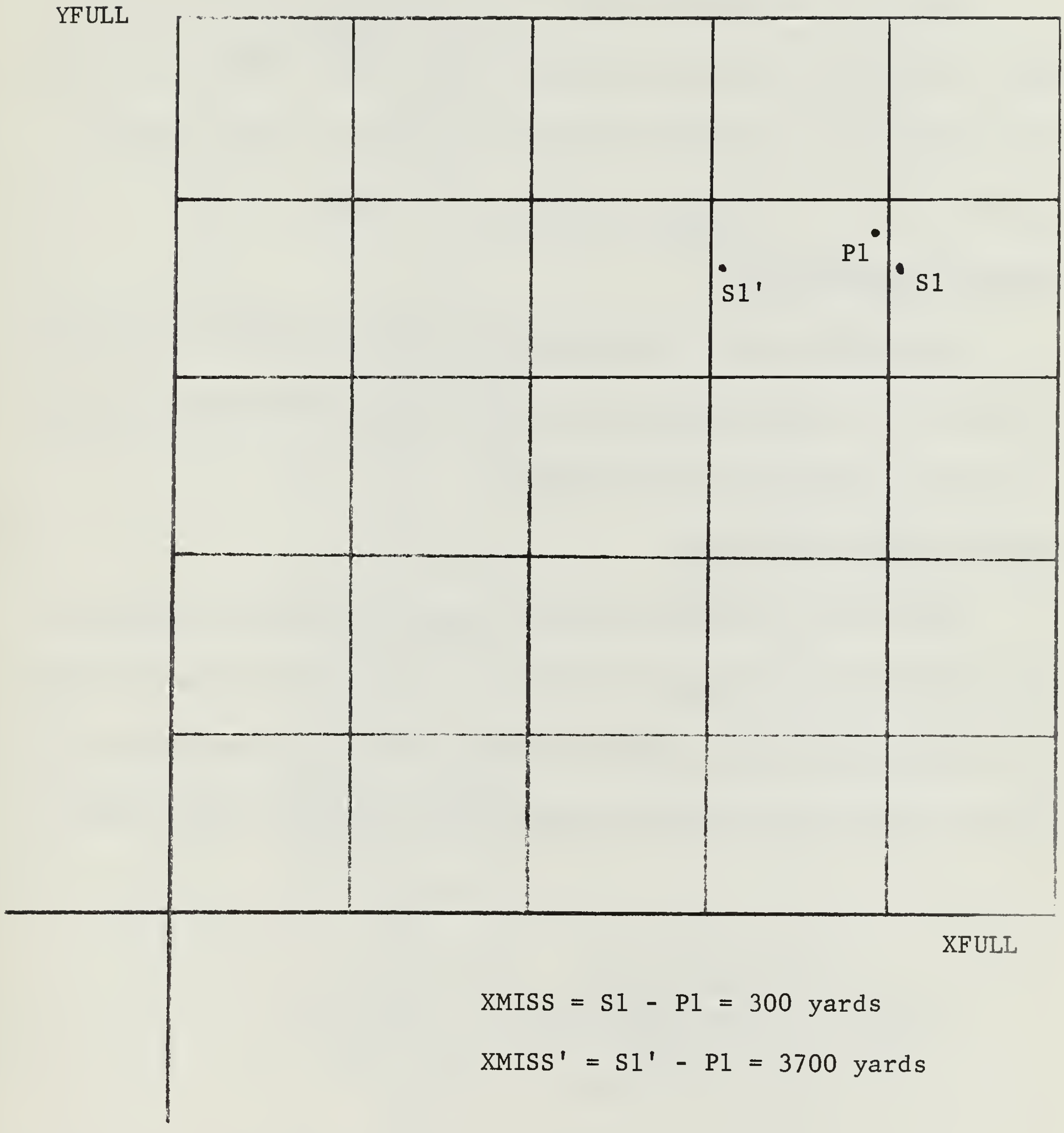


Fig. B-5-1 Flow graph of projectile detonation section



$$XMISS = S1 - P1 = 300 \text{ yards}$$

$$XMISS' = S1' - P1 = 3700 \text{ yards}$$

Fig. B-5-2 Segment map showing possible miss distance errors

APPENDIX B-6

FIRING SECTION

The firing section (Fig. B-6-1) stores the impact position and time. If the current round is the first round, exit is made to the splash timer; if not, exit is made to the end of run decision point, Sense Switch 6.

SPLASH COORDINATES

The quantities RX4, (X component of impact) RY4, (Y component of impact) R4, (polar component of impact) and NTOS (elapsed time of splash) are stored for each round fired.

FIRST ROUND CONDITION

When the first round is fired the splash timer must be turned on. After the first round splashes the timer is reinitialized by entry through the projectile detonation section. After the last round fired lands, the timer is turned off and the first-round condition flag is turned back on.

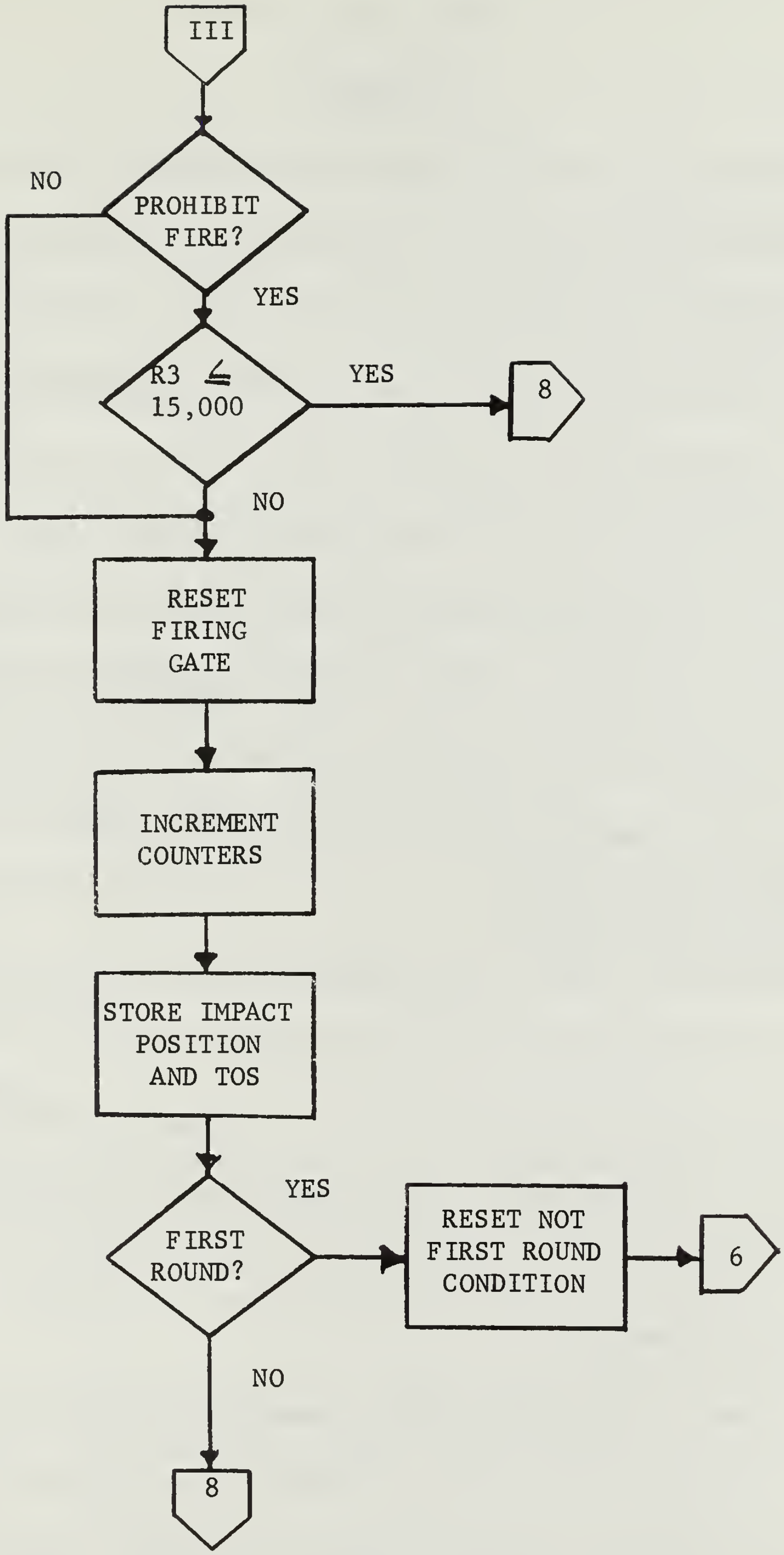


Fig. B-6-1 Flow graph of firing section

APPENDIX B-7

DISPLAYS

Displays are present at both the PT station and the DD station. The destroyer station has one oscilloscope that shows the last four shell splashes and another oscilloscope that shows the velocity vector and the true position of the PT boat. There is also provision to commence tracking, commence firing, change initial course and speed, and choose a spotting doctrine. The PT station has two oscilloscopes for the same purposes. The course and speed of the PT boat can be changed while the run is in progress by selecting any of five different speeds and various standard-rudder commands from the PT control console. An X-Y plotter is also present to record the track of the relative positions.

VELOCITY VECTOR DISPLAY

The velocity vector, as explained in Ref. 2, is made up with a full-wave rectified sine wave and multipliers.

The relative position (Fig. B-7-1) is obtained from the coarse integrators: A021 and A023. These integrators give position relative to the destroyer. For position relative to the PT boat, this signal is sent through inverters.

In order to show both of these quantities (velocity vector and relative position) on the same oscilloscope, two digital-to-analog switches are used for each set of deflection plates. The switches alternate the input to the deflection plates between the vector and the relative position at the rate of five hundred times per second. This presents flicker-free presentation of the two signals.

If a PT boat maneuver is detected at the DD, the relative position "dot" flashes off and on. This is at a rate of one Hz for a maneuver detected by position and ten Hz for a maneuver detected by velocity.

SPLASH DISPLAYS

The splash displays are both driven by the same signal (Fig. B-7-2). The inputs are on DAC lines which store the last four splashes. These splashes have been limited to two hundred yards. The DAC lines go into an external "black box" that has a two-channel set of four switches. A one-thousand-Hz counter controls the logic switching. This box controls the switching between each input leg and the output for one fourth of the time. In this way the output shows all four inputs with flicker-free presentation.

DIGITAL SWITCHES

The analog computer has a bank of eight digital switches. Five switches are used in this simulation. Switch 0 is used for a commence-tracking signal. Switch 1 is used as a firing switch. Switch 4,5, and 6 are used for spot procedure selection. The switches can be thought of as binary numbers, with their value being 1 when on and 0 when off. Switch 4 represents 2^2, Switch 5 2^1 and Switch 6 2^0. Spotting routine 4 is Switch 4 on, 5 off, and 6 off. This combination of three switches give a possibility of selecting eight different spotting procedures.

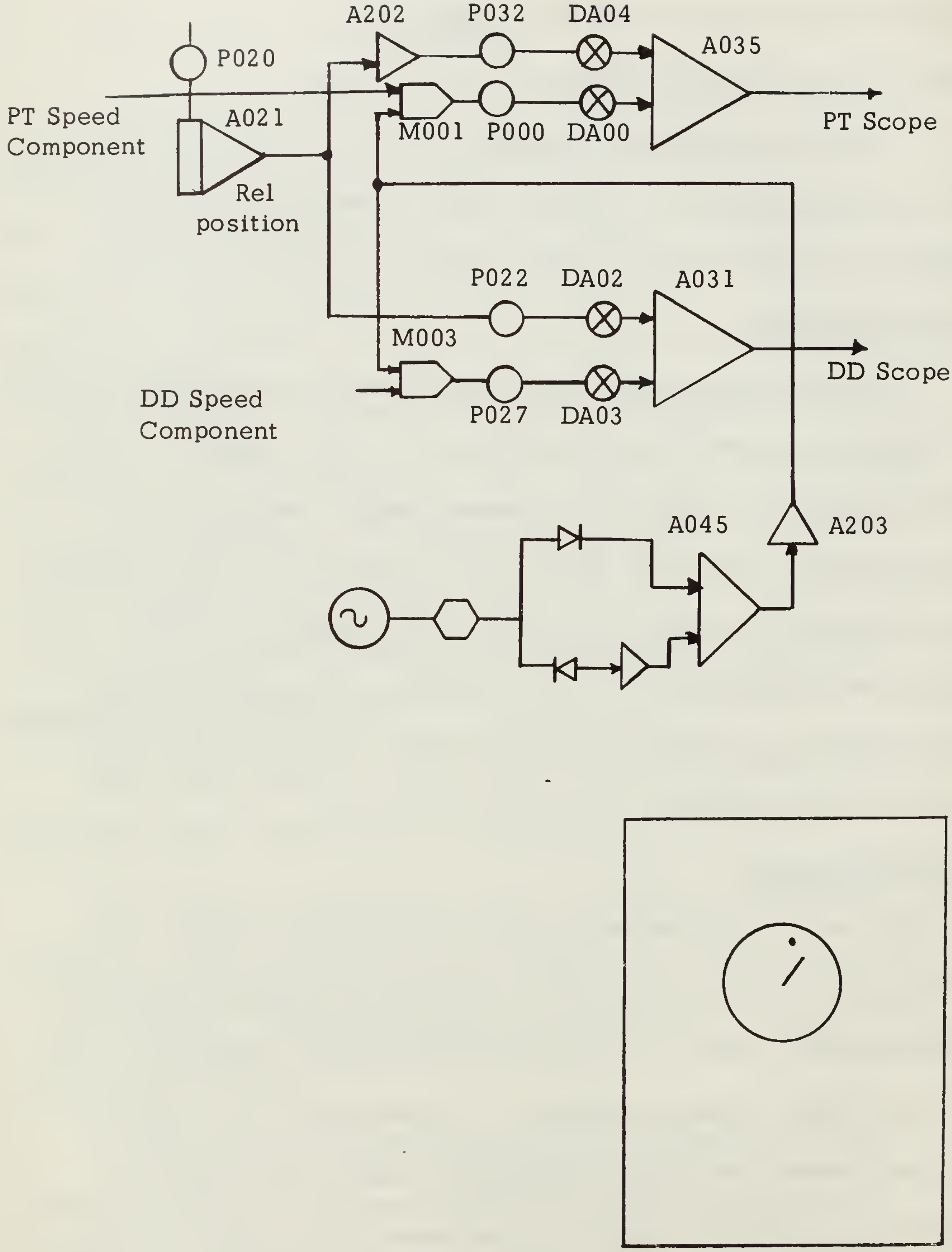
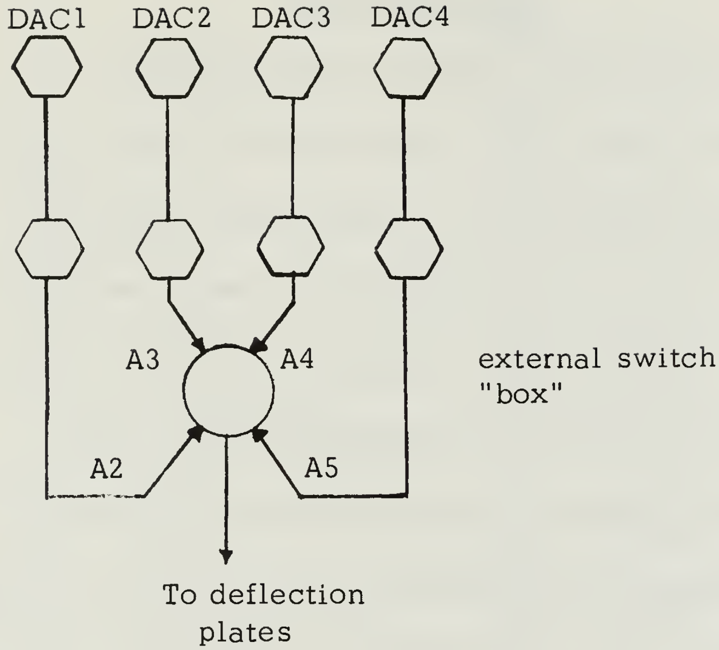
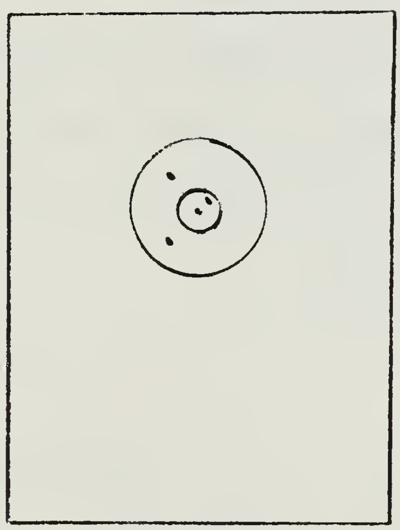


Fig. B-7-1 Speed display components and view





Splash display

outer circle = 200 yards
inner circle = 40 yards (hit)

Fig. B-7-2 Splash display components and view

APPENDIX B-8

DATA REDUCTION

Data is reduced after each run for that particular run. It is first sorted into each spotting mode. The following quantities are then calculated for each spotting mode: average miss distances X, Y, and R; mean-square value of miss distances X, Y, and R; variance of miss distances X, Y, and R; number of rounds fired; number of hits; percentage of hits; and minimum and maximum impact range.

An external program uses a one-card input for each run which consists of average miss distances, mean-square miss distances, number of rounds fired, number of hits, spotting mode used, and whether a maneuvering or non-maneuvering run. The output quantities for each spotting mode and maneuvering or non-maneuvering condition are: average miss distance X, Y, and R; mean-square miss distance X, Y, and R; variance of miss distance X, Y, and R; number of rounds fired; and percentage of hits.

Analog Computer Component Settings

Potentiometers

P000 - .1250	P020 - .8000
P001 - .5000	P021 - .0500
P002 - .1000	P022 - .0420
P003 - .9500	P023 - .7950
P004 - .0500	P024 - .9996
P005 - .1250	P025 - .8000
P006 - .1000	P026 - .9996
P007 - .9500	P027 - .3500
P010 - .7500	P030 - .0250
P011 - .5555	P031 - .0250
P012 - .3704	P032 - .0420
P013 - .0500	P033 - .1414
P014 - .3500	P034 - .1414
P015 - .5555	P035 - .0420
P016 - .3704	P036 - .0420
P017 - .0500	

Delay Flops

DF00 - .1 msec.	DF05 - .1 sec.
DF01 - .1 msec.	DF06 - .1 msec.
DF02 - .1 sec.	DF11 - 1 sec.
DF03 - .1 sec.	DF13 - 1 sec.
DF04 - .1 msec.	

Limiters

L00	± .1500	(A002)
L01	± .0750	(A010)
L02	± .0750	(A016)

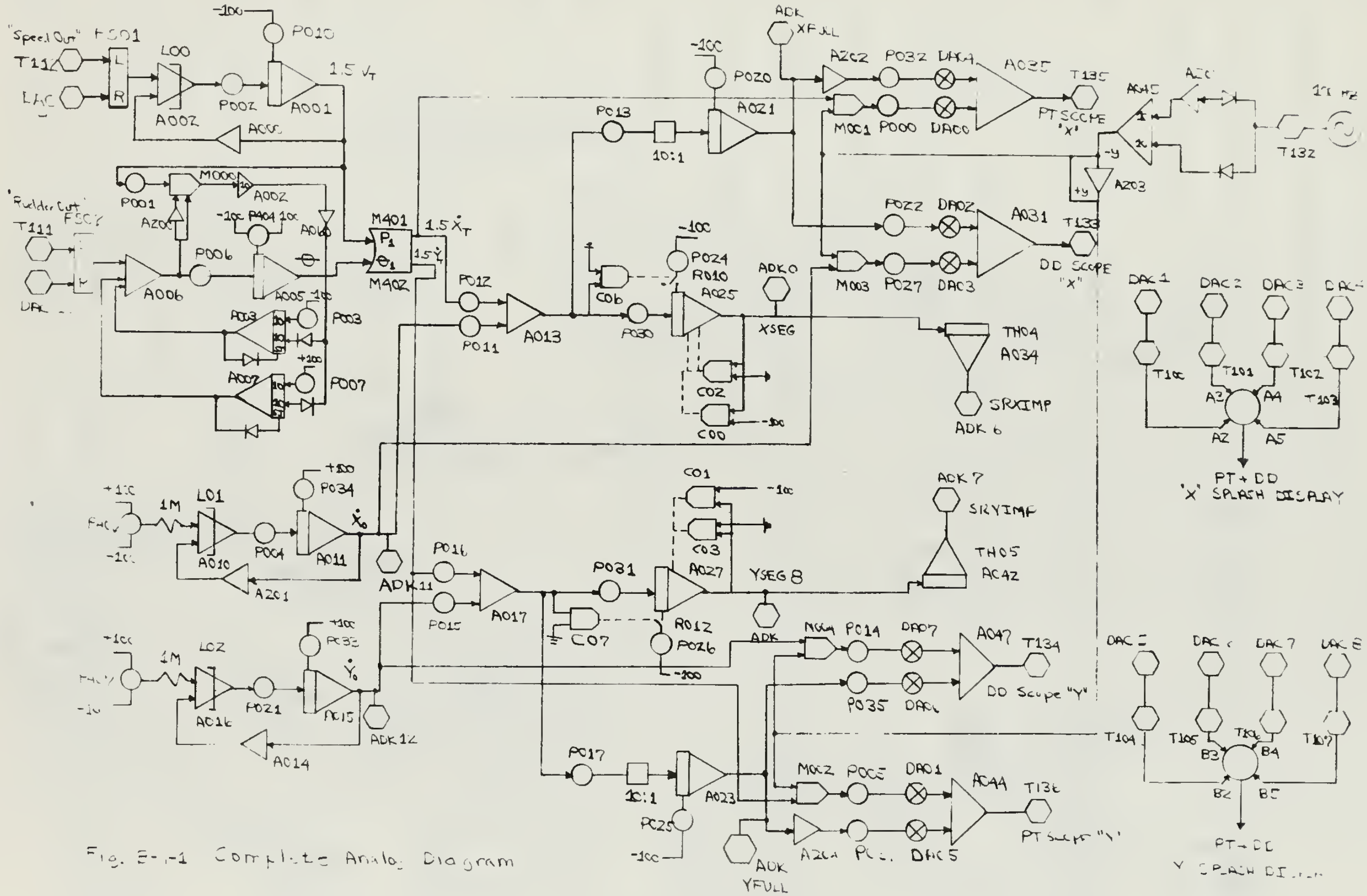
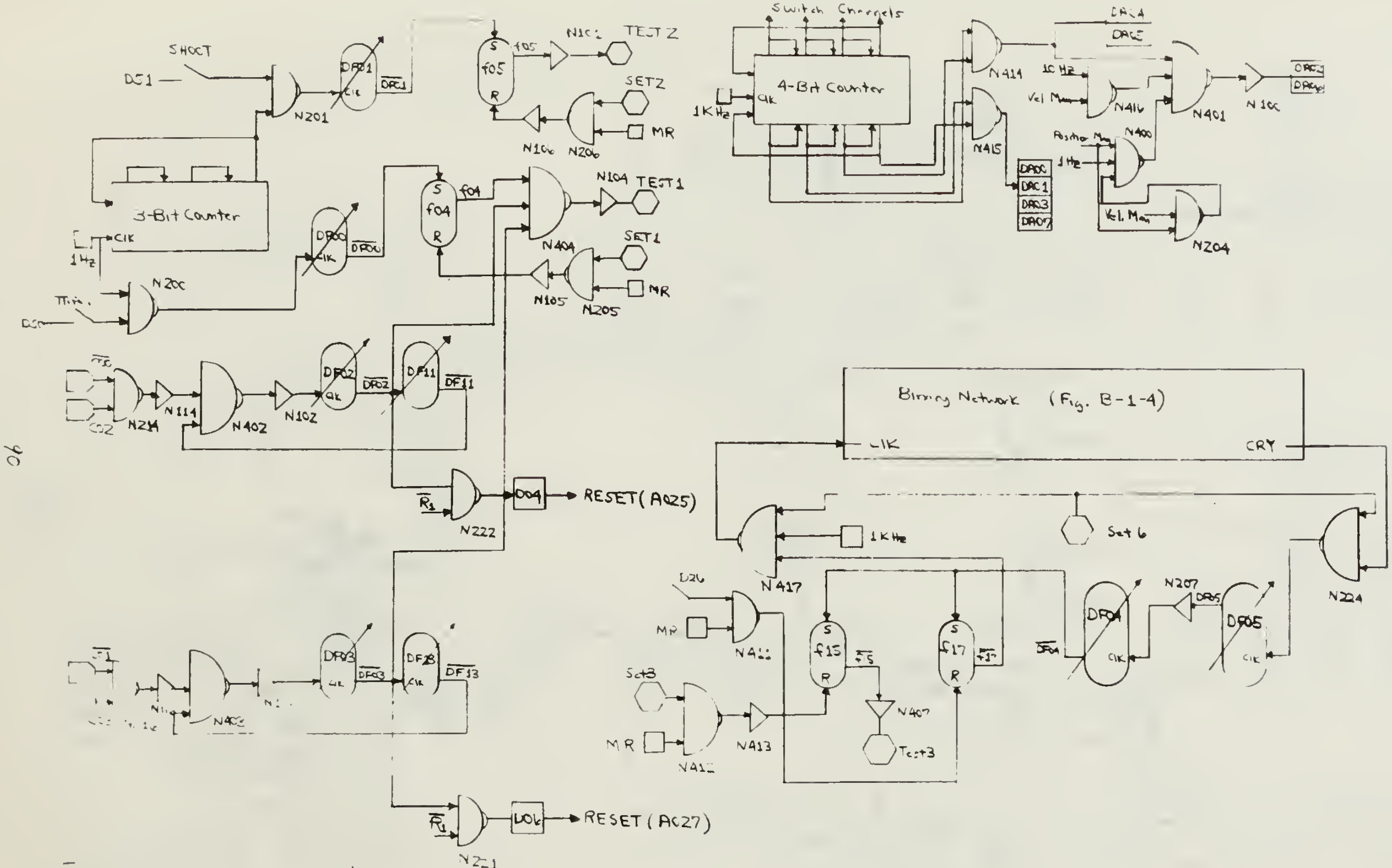


Fig. E-1 Complete Analog Diagram



SHOOT
N201
3-Bit Counter
CLK
1 Hz
N200
f05
N106
N206
TEST 2
SET2
MR
f04
N404
N104
TEST1
SET1
N105
N205
DF02
DF11
N114
N402
N102
N222
RESET(A025)
DF03
DF13
N221
RESET(A027)
Switch Channels
4-Bit Counter
1 K Hz
N414
N415
DAC0
DAC1
DAC3
DAC7
10 Hz
Vel Man
N416
N400
N401
N204
Vel. Man
Binning Network (Fig. B-1-4)
CLK
CRY
N417
1 K Hz
Set 6
N224
D26
MR
N411
Set3
MR
N412
N413
f15
f17
N407
Test3
DF04
N207
DF05

APPENDIX B-10

GLOSSARY

MAIN PROGRAM

ADK - analog to digital conversion

AVRR, AVRX, AVRY - average components of miss distance

AX, AY - dummies used for computing miss distance

AZ - noisy true-bearing angle

CT3 - fourth-degree polynomial curve-fit coefficients for time of flight

DAC - digital to analog conversion

DISPAR - fourth-degree polynomial curve-fit coefficients for dispersion variance

DRTX1, DRTY1 - relative components of range rate

HITS - number of hits (RMISS less than 40 yards)

I - projectiles fired counter

INOW - elapsed time from digital counter at splash-acknowledgement time

IT - elapsed time from maneuver timer

ITIME - elapsed time from digital timer at track time

ITNOW - time for next maneuver

J - analysis section index

JSHOT - projectiles in flight counter

JXY - analysis-plot storage vector

K - analysis section index

KNORM - logical SPOTNORM use indicator

KPROC - logical reprocess indicator

L - counter for indexing time to splash for splash-timer initial conditions

MISSCNT - counter for indexing miss-distance storage

MODE - vector storage of spotting routine used

N - index for analysis section

NCELLS - number of spaces in width of line-printer plot routine

NDAC - sequencing index for splash display

NIT - index for maneuver storage

NN - index for long-term-tracker data-point storage

NO - index for time-of-flight coefficients

NSPOTS - total number of spotting routines used

NTIME - time until next splash for splash-time counter

NTOS - vector storage of splash time

NTRKS - counter for total number of tracker data points

NX - gain schedule counter for ST tracker

NXSF, NYSF - coarse partition number for components of range

ORD - Y value for VPLOT

ORDN - X value for VPLOT

PART3 - partition values for time of flight

PARTDISP - partition values for dispersion variances

PERHIT - percentage of hits

R - distance from lower partition value to present position

R1,RX1,RY1 - present range components

R2,RX2,RY2 - predicted range components

R3,RX3,RY3 - impact range components without dispersion added

R4,RX4,RY4 - vector storage of impact range components with dispersion

R5,RX5,RY5 - impact range components with dispersion

R3MAX - maximum gun range

RCELL - width of X-plotting cell

RDRRNG - noisy polar range

RL - time-of-flight lookup criterion

RLOW - dummy for analysis plot

RMEANS,XMEANS,YMEANS - mean-square value of miss distances

RMIN - minimum impact range of a round

RMISS,XMISS,YMISS - vector storage of miss components

RMAX - maximum impact range of a round

ROTT - predicted polar range at torpedo impact

ROUNDS - rounds fired in specific spotting mode in analysis section

RUP - dummy for analysis plot

SRXIMP,SRYIMP - segment value of position at time of impact

T1 - first approximation of TOF

T2 - precise TOF for firing

VARDISP - variance for gun dispersion

VARR,VARX,VARY - variance components of miss distances

VOX,VOY - components of own-ship's speed in yd/sec

VOXIN,VOYIN - components of own-ship's speed in volts

XACT,YACT - actual rectangular components of range

XDISP,YDISP - rectangular components of gun dispersion

XFULL,YFULL - course components of range

XMISSO,YMISSO - components of miss distances sent out to displays

XNK,YNK - noisy rectangular range components

XSEG,YSEG - fine components of range

XSUM,YSUM - LT-tracker range-component accumulator

XY - vector storage for VPLOT output

SUBROUTINE ADSPOT

TESTX1,TESTY1 - test to establish difference between LT and ST tracker velocity for this measurement.

TESTX2,TESTY2 - test to establish difference between LT and ST tracker velocity for last measurement.

TESTX3,TESTY3 - test to determine if the two successive differences were of the same sign.

VELX1,VELX3,VELY1,VELY3 - ST tracker velocity

VELX2,VELX4,VELY2,VELY4 - LT tracker velocity

SUBROUTINE MANEUVER

ITNOW - elapsed time of next maneuver

NIT - sequencing index

NITNOW - vector storage for next maneuver time

NORDCO - vector storage for rudder-command sequence

NORDSP - vector storage for speed orders

ORDCO - vector storage for rudder-control voltage value

ORDSP - vector storage for speed-control voltage value

SUBROUTINE PLOOK

I - index for segment search

NO - base index for TOF calculations

PARNO - segment index

PART - vector storage for partition values

R - magnitude of range from partition boundary to target

R3 - polar value of ballistic range

R3MAX - maximum ballistic range of gun

SUBROUTINE RACT

ACTR - full-range value from main program (XFULL or YFULL)

ACTSEG - segmented value from main program (XSEG or YSEG)

NSF - segment identification number

PARSEG - storage vector for partition values

RAC - composite value of range for main program (XACT or YACT)

SUBROUTINE RANDSPT

VPTX,VPTY - X and Y components of PT velocity in yds/sec

BRNG - true bearing to target in radians

BY - true bearing to target with spot included, in radians

RSPOT - uniform range spot

STDB - standard deviation in bearing

W - random number with uniform probability density function

SUBROUTINE RDRNOISE

AZ - noisy bearing in radians

BNOISE - gaussian noise in bearing

RDRRNG - noisy polar range

RNOISE - gaussian noise in range

XNK,YNK - noisy X and Y components of range

SUBROUTINE SPOTNORM

BRNG - true target bearing

BSPOT - amount of bearing spot to be applied

NBSP - number of the bearing spot to be applied

NRSPOT - number of the range spot to be applied

R1 - present polar range

RSPOT - amount of range spot to be applied

RX1,RY1 - rectangular components of present range after spots applied

SUBROUTINE TIMER

LSET - initialization level for the setlines

N - input value for timer

NC1,NC2 - intermediate values for input as determined with decimal-to-binary algorithym

SUBROUTINE TRACKER

DETR - reprocessing-criterion magnitude

DRTX1,DRTY1 - relative velocity in yd/sec

GP - vector storage of position gain schedule

GV - vector storage of velocity gain schedule

KPROC - logical reprocessing flag

NBAND - switch for gain schedules at 15 thousand yards

NFLAG - flag of output selection determination

NN - LT tracker data counter

NTRKS - counter for total tracks

NX - gain-schedule index

R1,RX1,RY1 - components of present range

RDRRNG - noisy present range

TESTX1,TESTY1 - absolute value of difference between predicted position and actual position of this measurement

TESTX2,TESTY2 - absolute value of difference between predicted position and actual position for last measurement

TESTX3,TESTY3 - absolute value for last two tests (sign check)

TXSUM,TYSUM - accumulator for total data points for LT tracker

XI,YI - vector storage for LT tracker data points

XNK,YNK - noisy rectangular components of range

XS,YS - state vectors for ST tracker

Row 1 - now, 2 - now minus 1, 3 - now minus 2, 4 - now minus three

Column 1 - noisy position, 2 - filtered position, 3 - filtered velocity, 4 - predicted position

XSUM,YSUM - intermediate accumulator for LT tracker data points

XPLT,YPLT - position output from LT tracker

XVLT,YVLT - velocity output from LT tracker

SUBROUTINE WRCIRCLE

A,B - linear coefficients for translation of center of weapons-release circle

CO - own-ship's course

OFFSET,XOFF,YOFF - components of circle translation

ROTT,OTTX,OTTY - position coordinates at time of torpedo intercept

VO,VOX,VOY - components of own-ship's velocity

```
C***********************************************************************
C                                                                      *
C                       INITIALIZATION SECTION - IS                    *
C                                                                      *
C***********************************************************************
      DIMENSION CT3(32), PART3(8), PARTDISP(8), DISPVAR(32),            IS
     *XMISS(500), YMISS(500), RMISS(500), RX4(500), RY4(500), R4(500),  IS
     *NTOS(500),MODE(500), JXY(2), XY(100,2)                            IS
      COMMON /TRKTOADP/VELX1,VELX2,VELX3,VELX4,VELY1,VELY2,VELY3,VELY4
      COMMON /RELMOTION/ DRTX1, DRTY1, VOX, VOY, RX1, RY1, R1, T1       IS
      COMMON/TRKCOM/NN,NTRKS,NX,XSUM,TXSUM,YSUM,TYSUM,KPROC             IS
      LOGICAL KFIRST,KPROC,KNORM                                        IS
C                                                                       IS
C     STORE PRECOMPUTED QUANTITIES                                      IS
C                                                                       IS
C          FOURTH DEGREE POLYNOMIAL COEFFICIENTS FOR TIME OF FLIGHT     IS
C                                                                       IS
      DATA CT3/                                                         IS
     *-0.292968749E-02,0.120663642E-02, 0.313593773E-07,0.177990955E-11,IS
     *0.127812499E+02 ,0.206625461E-02, 0.830186763E-07,0.229505303E-11,IS
     *0.216748046E+02 ,0.277590751E-02, 0.844884198E-07,-.380140363E-11,IS
     *0.316220703E+02 ,0.322687625E-02, 0.617001205E-07,0.443911574E-11,IS
     *0.434804687E+02 ,0.383782386E-02, 0.911386450E-07,0.264535060E-10,IS
     *0.555166015E+02 ,0.508844852E-02, 0.172774889E-06,0.207116102E-09,IS
     *0.656855468E+02 ,0.787496566E-02, 0.779982656E-07,0.366708263E-08,IS
     *0.724999999E+02 ,0.346832275E-01,-0.303983688E-03,0.114162685E-05/IS
C                                                                       IS
C          DISPERSION VARIANCES                                         IS
C                                                                       IS
      DATA DISPVAR/                                                     IS
     *    86.0,     -0.003,     0.0,       0.0,                         IS
     *    80.0,     -0.0065,    0.0,       0.0,                         IS
     *    67.0,     -0.005,     0.0,       0.0,                         IS
     *    57.0,     -0.003,     0.0,       0.0,                         IS
     *    52.0,      0.0,       0.0,       0.0,                         IS
     *    52.0,      0.003,     0.0,       0.0,                         IS
```

```
     *    57.0,      0.006,    0.0,      0.0,                                 IS
     *    98.C,      0.005,    0.0,      0.0/                                 IS
C                                                                             IS
C          RANGE SEGMENT PARTITIØNS FØR TØF                                   IS
C                                                                             IS
      DATA PART3/                                                             IS
     *    0.0,       8100.0,   11800.0,  15100.0,  18500.0, 21300.0,          IS
     *    23000.0,  23700.0/                                                  IS
C                                                                             IS
C          RANGE SEGMENT PARTITIØNS FØR DISPERSIØN VARIANCES                  IS
C                                                                             IS
      DATA PARTDISP/                                                          IS
     *    0.0,       1000.0,   4000.0,   8000.0,   9000.0,                    IS
     *    11000.0,  18000.0,  21000./                                         IS
C                                                                             IS
C          INITIALIZE CØNSTANTS                                               IS
C                                                                             IS
      DATA NCELLS/100/NDAC/0/NSPØTS/4/R3MAX/23700./RL/1.0/                    IS
     *XMISSØ/-.6/YMISSØ/-.6/                                                  IS
C                                                                             IS
C     RESET CØUNTERS FØR NEXT RUN                                             IS
C                                                                             IS
C                                                                             IS
C          FIRING CØUNTERS                                                    IS
C                                                                             IS
  100 I=0;KFIRST=.FALSE.;L=0;MISSCNT=0;JSHØT=0;IT=0;NIT=1;ITNØW=1             IS
      KNØRM=.FALSE.                                                           IS
C                                                                             IS
C          ADAPTIVE SPØT QUANTITIES                                           IS
C                                                                             IS
      VELX1=0.0;VELX2=0.0;VELX3=0.0;VELX4=0.0;VELY1=0.0;VELY2=0.0             IS
      VELY3=0.0;VELY4=0.0                                                     IS
C                                                                             IS
C          NØRMAL SPØT CØUNTERS                                               IS
C                                                                             IS
      NRSPØT=1; NBSP=1                                                        IS
```

```
C                                                                       IS
C          TRACKER QUANTITIES                                           IS
C                                                                       IS
      NN=0;NTRKS=0;NX=0;XSUM=0.0;TXSUM=0.0;YSUM=0.0;TYSUM=0.0           IS
      KPRØC=.FALSE.                                                     IS
C                                                                       IS
C     INITIALIZE DAC LINES AND SETLINES                                 IS
C                                                                       IS
      CALL DAC(1,XMISSØ,2,YMISSØ,3,XMISSØ,4,YMISSØ,5,XMISSØ,6,YMISSØ,   IS
     *7,XMISSØ,8,YMISSØ,9,0.0,10,0.0)                                   IS
      CALL SETLINES(1,-1,2,-1,3,-1,4,1,5,1,6,1,8,-1,9,1,26,1)           IS
C                                                                       IS
C     INITIALIZE CLØCK                                                  IS
C                                                                       IS
      CALL WRITECLØCK(0)                                                IS
      CALL RESET                                                        IS
      PAUSE 1
C**********************************************************************
C                                                                     *
C                           START SECTIØN - ST                        *
C                                                                     *
C**********************************************************************
      XMISSØ=0.0                                                        ST
      YMISSØ=0.0                                                        ST
      CALL DAC(1,XMISSØ,2,YMISSØ,3,XMISSØ,4,YMISSØ,5,XMISSØ,6,YMISSØ,   ST
     *7,XMISSØ,8,YMISSØ)                                                ST
      CALL CØMPUTE                                                      ST
C                                                                       ST
C     START THE CLØCK                                                   ST
C                                                                       ST
      CALL STARTCLØCK                                                   ST
C
C     ØNE SECØND TIMING TEST TØ ENTER PP SECTIØN
C
    1 IF(TEST(1) .NE. -1) GØ TØ 1
C
```

```
C*****************************************************************
C                                                                *
C                  PRESENT PØSITIØN SECTIØN - PP                 *
C                                                                *
C*****************************************************************
C                                                                 PP
C     CLØSE GATE AND CALL IN PRESENT PØSITIØN                     PP
C                                                                 PP
      CALL SETLINES(1,1)                                          PP
      CALL SETLINES(1,-1)                                         PP
      CALL ADK(0,XSEG,4,YSEG,8,XFULL,9,YFULL,10,VØXIN,11,VØYIN)   PP
C                                                                 PP
C     CØMPUTE ACTUAL RANGE FRØM SEGMENTED INFØRMATIØN             PP
C                                                                 PP
      CALL RACT(XFULL,XSEG,XACT,NXSF)                             PP
      CALL RACT(YFULL,YSEG,YACT,NYSF)                             PP
      CALL READCLØCK(ITIME)                                       PP
C                                                                 PP
C     SCALE ØWN SHIPS SPEED                                       PP
C                                                                 PP
      VØX=VØXIN*56.3                                              PP
      VØY=VØYIN*56.3                                              PP
C                                                                 PP
C     ADD RADAR NØISE TØ PØSITIØN INPUTS                          PP
C                                                                 PP
      CALL RDRNØISE(XACT,YACT,XNK,YNK,RDRRNG,AZ)                  PP
C                                                                 PP
C     SEND NØISY RANGES TØ TRACKER FØR SMØØTHING                  PP
C                                                                 PP
      CALL TRACKER(XNK,YNK,RDRRNG)                                PP
      WRITE(108,60) RX1,RY1,DRTX1,DRTY1,R1                        PP
   60 FØRMAT(1X,$RX1=$,F10.2,5X,$RY1=$,F10.2,5X,$DRTX1=$,F8.2,5X, PP
     *$DRTY1=$,F8.2,5X,$R1=$,F10.2)                               PP
C                                                                 PP
C     PRØGRAM MANEUVER                                            PP
C                                                                 PP
```

```
      IT=IT+1                                                          PP
      IF(IT .EQ. ITNOW) CALL MANEUVER(NIT,ITNOW)                       PP
C                                                                      PP
C     DETERMINE IF PT HAS PENETRATED W R ENVELOPE IN GAME MODE         PP
C                                                                      PP
      IF(SENSE SWITCH 4) 101,102                                       PP
  101 CALL WRCIRCLE(ROTT)                                              PP
      IF(ROTT .LE. 10000.) GO TO 9                                     PP
C
C     INDICATE IF OUT OF RANGE CONDITION AND SKIP BALLISTIC SECTION
C
  102 IF (R1 .GT. 20000.0) CALL SETLINES(8,-1); GO TO 4
      CALL SETLINES(8,1)
C**********************************************************************
C                                                                     *
C                           SPOT SELECTION SECTION - SS               *
C                                                                     *
C**********************************************************************
C                                                                      SS
C            NORMAL SPOT 001                                           SS
C                                                                      SS
      IF (TEST(4) .EQ.  1 .AND. TEST(5) .EQ.  1 .AND. TEST(6) .EQ. -1) SS
     *       CALL SPOTNORM(NRSPOT,NBSP);                               SS
     *       KNORM=.TRUE.;                                             SS
     *       MODE(I)=1;                                                SS
     *       GO TO 2                                                   SS
C                                                                      SS
C            NO SPOT 010                                               SS
C                                                                      SS
      IF (TEST(4) .EQ.  1 .AND. TEST(5) .EQ. -1 .AND. TEST(6) .EQ.  1) SS
     *       MODE(I)=2;                                                SS
     *       GO TO 2                                                   SS
C                                                                      SS
C            RANDOM SPOT 011                                           SS
C                                                                      SS
      IF (TEST(4) .EQ.  1 .AND. TEST(5) .EQ. -1 .AND. TEST(6) .EQ. -1) SS
```

```
     *      CALL RANDSPT;
     *      MØDE(I)=3;                                                      SS
     *      GØ TØ 2                                                         SS
C                                                                           SS
C           ADAPTIVE SPØT 100                                               SS
C                                                                           SS
      IF (TEST(4) .EQ. -1 .AND. TEST(5) .EQ.  1 .AND. TEST(6) .EQ.  1)      SS
     *      CALL ADPSPØT;                                                   SS
     *      MØDE(I)=4;                                                      SS
     *      GØ TØ 2                                                         SS
C***********************************************************************
C                                                                      *
C                            BALLISTIC SECTIØN - BS                    *
C                                                                      *
C***********************************************************************
C                                                                           BS
C           TABLE LØØKUP FØR TIME ØF FLIGHT                                 BS
C                                                                           BS
    2 CALL PLØØK (PART3, R1, R3MAX, NØ,R)                                   BS
      T1=CT3(NØ)+R*(CT3(NØ+1)+R*(CT3(NØ+2)+R*CT3(NØ+3)))                    BS
      RX2=RX1+T1*DRTX1                                                      BS
      RY2=RY1+T1*DRTY1                                                      BS
      R2=SQRT((RX2**2)+(RY2**2))                                            BS
      REPEAT 3,  WHILE ABS(R3-R2) .GE. RL                                   BS
      CALL PLØØK(PART3, R2, R3MAX, NØ, R)                                   BS
      T2=CT3(NØ)+R*(CT3(NØ+1)+R*(CT3(NØ+2)+R*CT3(NØ+3)))                    BS
      RX3=RX1+T2*DRTX1                                                      BS
      RY3=RY1+T2*DRTY1                                                      BS
      R3=SQRT((RX3**2)+(RY3**2))                                            BS
    3 R2=R3-((R3-R2)/2.0)                                                   BS
C                                                                           BS
C           DETERMINE AND ADD GUN DISPERSIØN                                BS
C                                                                           BS
      CALL PLØØK(PARTDISP, R3, R3MAX, NØ, R)                                BS
      VARDISP=DISPVAR(NØ)+R*DISPVAR(NØ+1)                                   BS
      CALL GAUSS(VARDISP,0.0,XDISP)                                         BS
```

```
      CALL GAUSS(VARDISP,0.0,YDISP)                                     BS
      RX5=RX3+0.5*XDISP                                                 BS
      RY5=RY3+0.5*YDISP                                                 BS
      R5=SQRT((RX5**2)+(RY5**2))                                        BS
C
C     PROJECTILE DETONATION TEST TO ENTER PD SECTION
C
    4 IF (TEST(3) .EQ. 1) GO TO 7
C
C***********************************************************************
C                                                                     *
C                        PROJECTILE DETONATION SECTION - PD          *
C                                                                     *
C***********************************************************************
C                                                                       PD
C          RESET SPLASH GATE                                            PD
C                                                                       PD
      CALL SETLINES(3,1)                                                PD
      CALL SETLINES(3,-1)                                               PD
C                                                                       PD
C          CALL IN IMPACT POSITION                                      PD
C                                                                       PD
      CALL ADK(5,SRXIMP,6,SRYIMP)                                       PD
C                                                                       PD
C          INCREMENT  MISS COUNT                                        PD
C                                                                       PD
      MISSCNT=MISSCNT+1                                                 PD
C                                                                       PD
C          COMPUTE MISS DISTANCE                                        PD
C                                                                       PD
      IF(NXSF .GE. 6) AX=NXSF-SRXIMP-6.0                                PD
      IF(NXSF .LT. 6) AX=SRXIMP-NXSF+6.0                                PD
      XMISS(MISSCNT)=RX4(MISSCNT)-(AX*4000.0)                           PD
      IF(XMISS(MISSCNT) .GT. 3000.) XMISS(MISSCNT)=XMISS(MISSCNT)-4000. PD
      IF(XMISS(MISSCNT) .LT. -3000.) XMISS(MISSCNT)=XMISS(MISSCNT)+4000.PD
      IF(NYSF .GE. 6) AY=NYSF-SRYIMP-6.0                                PD
```

```
      IF(NYSF .LT. 6) AY=SRYIMP-NYSF+6.0                                  PD
      YMISS(MISSCNT)=RY4(MISSCNT)-(AY*4000.0)                             PD
      IF(YMISS(MISSCNT) .GT. 3000.) YMISS(MISSCNT)=YMISS(MISSCNT)-4000.  PD
      IF(YMISS(MISSCNT) .LT. -3000.) YMISS(MISSCNT)=YMISS(MISSCNT)+4000.PD
      RMISS(MISSCNT)=SQRT((XMISS(MISSCNT)**2)+(YMISS(MISSCNT)**2))       PD
C                                                                         PD
C          INCREMENT SPLASH INDEX                                         PD
C                                                                         PD
      L=L+1                                                               PD
C                                                                         PD
C          LIMIT ØUTPUT MISS DISTANCE TØ 200 YARDS                        PD
C                                                                         PD
      XMISSØ=-XMISS(MISSCNT)/333.333                                      PD
      IF(XMISSØ .GE. .6) XMISSØ=.6                                        PD
      IF (XMISSØ .LE. -.6) XMISSØ=-.60                                    PD
      YMISSØ=-YMISS(MISSCNT)/333.333                                      PD
      IF(YMISSØ .GE. .6) YMISSØ=.6                                        PD
      IF (YMISSØ .LE. -.6) YMISSØ=-.60                                    PD
      WRITE(108,66) MISSCNT,MØDE(MISSCNT),XMISS (MISSCNT),YMISS(MISSCNT)PD
     *,RMISS(MISSCNT),R4(MISSCNT)                                         PD
   66 FØRMAT(1X,$RØUND NUMBER   $,I3,5X,$SPØTTING MØDE  $,I1,5X,$XMISS=$PD
     *,F8.2,5X,$YMISS=$,F8.2,5X,$RMISS=$,F8.2,5X,$R4=$,F10.2)             PD
C                                                                         PD
C          DECREASE PRØJECTILES IN FLIGHT CØUNT                           PD
C                                                                         PD
      JSHØT=JSHØT-1                                                       PD
C                                                                         PD
C          ARE THERE ANY PRØJECTILES STILL IN FLIGHT                      PD
C                                                                         PD
      IF ( JSHØT .LE. 0 )                                                 PD
     *     CALL SETLINES(26,1);                                           PD
     *     CALL SETLINES(6,1,26,-1);                                      PD
     *     KFIRST=.FALSE.;                                                PD
     *     GØ TØ 5                                                        PD
    6 CALL READCLØCK(INØW)                                                PD
      NTIME=((NTØS(L)-INØW)*1000)/60
```

```
      CALL TIMER(NTIME)                                                PD
    5 NDAC=NDAC+1                                                      PD
      IF(NDAC .EQ. 1) CALL DAC(1,XMISS0,2,YMISS0)                      PD
      IF(NDAC .EQ. 2) CALL DAC(3,XMISS0,4,YMISS0)                      PD
      IF(NDAC .EQ. 3) CALL DAC(5,XMISS0,6,YMISS0)                      PD
      IF(NDAC .EQ. 4) CALL DAC(7,XMISS0,8,YMISS0) ; NDAC=0             PD
C                                                                      PD
C     DETERMINE IF PT HAS BEEN HIT IN GAME MODE                        PD
C                                                                      PD
      IF(SENSE SWITCH 4) 103,7                                         PD
  103 IF(RMISS(MISSCNT) .LE. 40.0 .AND. MISSCNT .GE. 1) GO TO 9        PD
C
C     THREE SECOND TIME TEST TO ENTER FIRING SECTION
C
    7 IF (TEST(2) .NE. -1.0 .OR. R1 .GT. 20000.) GO TO 8
C
C*********************************************************************
C                                                                    *
C                         FIRING SECTION - FS                        *
C                                                                    *
C*********************************************************************
C                                                                      FS
C     PROHIBIT FIRING LESS THAN 15,0000 YARDS OPTION                   FS
C                                                                      FS
      IF(SENSE SWITCH 3) 104,105                                       FS
  104 IF(R3 .LE. 15000.) GO TO 8                                       FS
  105 CONTINUE                                                         FS
C                                                                      FS
C            CLOSE FIRING TIMING GATE                                  FS
C                                                                      FS
      CALL SETLINES(2,1)                                               FS
      CALL SETLINES(2,-1)                                              FS
C                                                                      FS
C            INCREMENT SPOTNORM COUNTERS IF USED                       FS
C                                                                      FS
      IF(KNORM)                                                        FS
```

```
      *     KNORM=.FALSE.;                                               FS
      *     IF(NRSPOT .EQ. 2) NBSP=NBSP+1;                               FS
      *     IF(NRSPOT .EQ. 3) NRSPOT=0;                                  FS
      *     NRSPOT=NRSPOT+1;                                             FS
      *     IF(NRSPOT .EQ. 3 .AND. NBSP .EQ. 4) NBSP=1                   FS
C                                                                        FS
C           INCREMENT PROJECTILE IN FLIGHT COUNT                         FS
C                                                                        FS
      JSHOT=JSHOT+1                                                      FS
C                                                                        FS
C           INCREMENT ROUNDS FIRED                                       FS
C                                                                        FS
      I=I+1                                                              FS
      WRITE(108,65) I,R1,R3                                              FS
   65 FORMAT(1X,$ROUND NO.$,I4,2X,$FIRED$,5X,$R1=$,F10.2,5X,$R3=$,       FS
     *F10.2)                                                             FS
      IF (I .EQ. 450) WRITE(102,202) I                                   FS
  202 FORMAT($ CAUTION ARRAY ALMOST FILLED $,2X,I4)                      FS
C                                                                        FS
C           PLACE THE SPLASH COORD AND TIME IN PROJ-IN-FLIGHT ARRAY      FS
C                                                                        FS
      RX4(I)=RX5                                                         FS
      RY4(I)=RY5                                                         FS
      R4(I)=R5                                                           FS
      NTOS(I)=ITIME+(60.*T2)
C                                                                        FS
C           TAKE CARE OF FIRST ROUND FIRED CONDITION                     FS
C                                                                        FS
      IF(.NOT. KFIRST)                                                   FS
      *     L=L+1;                                                       FS
      *     KFIRST=.TRUE.;                                               FS
      *     GO TO 6                                                      FS
C
C     END RUN OPTION TO ENTER ANALYSIS SECTION
C
    8 IF(SENSE SWITCH 6) 9,1
```

```
C
C***********************************************************************
C                                                                      *
C                       ANALYSIS SECTIØN - AS                          *
C                                                                      *
C***********************************************************************
C                                                                       AS
C     DATA ANALYSIS SECTIØN                                             AS
C                                                                       AS
    9 JXY(1)=1                                                          AS
      JXY(2)=2                                                          AS
      CALL STØPCLØCK                                                    AS
      DØ 25 K=1,NSPØTS                                                  AS
C                                                                       AS
C     INITIALIZE STATISTICS STØRAGE QUANTITIES                          AS
C                                                                       AS
      RØUNDS=0.0                                                        AS
      HITS=0.0                                                          AS
      RMIN=25000.                                                       AS
      RMAX=0.0                                                          AS
      AVRX=0.0                                                          AS
      AVRY=0.0                                                          AS
      AVRR=0.0                                                          AS
      XMEANS=0.0                                                        AS
      YMEANS=0.0                                                        AS
      RMEANS=0.0                                                        AS
      DØ 21 J=1,MISSCNT                                                 AS
C                                                                       AS
C     BYPASS IF WRØNG SPØTTING MØDE                                     AS
C                                                                       AS
      IF (MØDE(J) .NE. K) GØ TØ 21                                      AS
C                                                                       AS
C     INCREMENT RØUNDS FIRED                                            AS
C                                                                       AS
      RØUNDS=RØUNDS+1.0                                                 AS
C                                                                       AS
```

```
C     ADD TO AVERAGE AND VARIANCE TOTALS                              AS
C                                                                     AS
      AVRX=AVRX+XMISS(J)                                              AS
      AVRY=AVRY+YMISS(J)                                              AS
      AVRR=AVRR+RMISS(J)                                              AS
      XMEANS=XMEANS+XMISS(J)**2                                       AS
      YMEANS=YMEANS+YMISS(J)**2                                       AS
      RMEANS=RMEANS+RMISS(J)**2                                       AS
C                                                                     AS
C     FIND MIN AND MAX VALUES OF FIRING RANGE                         AS
C                                                                     AS
      IF (R4(J) .LT. RMIN) RMIN=R4(J)                                 AS
      IF (R4(J) .GT. RMAX) RMAX=R4(J)                                 AS
C                                                                     AS
C     DETERMINE IF A HIT, INCREMENT HIT COUNT IF NECESSARY            AS
C                                                                     AS
      IF(RMISS(J) .LE. 40.0) HITS=HITS+1.0                            AS
   21 CONTINUE                                                        AS
C                                                                     AS
C     BYPASS IF NO ROUNDS FIRED IN THIS MODE                          AS
C                                                                     AS
      IF(ROUNDS .LE. 0) GO TO 25                                      AS
C                                                                     AS
C     COMPUTE AND STORE MEANS AND VARIANCES                           AS
C                                                                     AS
      AVRX=AVRX/ROUNDS                                                AS
      AVRY=AVRY/ROUNDS                                                AS
      AVRR=AVRR/ROUNDS                                                AS
      XMEANS=XMEANS/ROUNDS                                            AS
      YMEANS=YMEANS/ROUNDS                                            AS
      RMEANS=RMEANS/ROUNDS                                            AS
      VARX=XMEANS-ABS(AVRX**2)                                        AS
      VARY=YMEANS-ABS(AVRY**2)                                        AS
      VARR=RMEANS-ABS(AVRR**2)                                        AS
C                                                                     AS
C     COMPUTE PERCENTAGE OF HITS                                      AS
```

```
      PERHIT=(HITS/RØUNDS)*100.                                         AS
C                                                                       AS
C     PRINT ØUTPUTS                                                     AS
C                                                                       AS
      WRITE(108,50) K                                                   AS
   50 FØRMAT(1H1,$RESULTS FØR SPØTTING MØDE$,I2)                        AS
      WRITE(108,51) AVRX,XMEANS,VARX                                    AS
   51 FØRMAT(1H0,$AVER X MISS DIST=$,F8.2,3X,$MEAN SQ X MISS DIST =$,   AS
     *F8.0,3X,$VAR X MISS DIST =$,F8.0)                                 AS
      WRITE(108,52) AVRY,YMEANS,VARY                                    AS
   52 FØRMAT(1H0,$AVER Y MISS DIST=$,F8.2,3X,$MEAN SQ Y MISS DIST =$,   AS
     *F8.0,3X,$VAR Y MISS DIST =$,F8.0)                                 AS
      WRITE(108,53) AVRR,RMEANS,VARR                                    AS
   53 FØRMAT(1H0,$AVER R MISS DIST=$,F8.2,3X,$MEAN SQ R MISS DIST =$,   AS
     *F8.0,3X,$VAR R MISS DIST =$,F8.0)                                 AS
      WRITE(108,54) HITS,RØUNDS,PERHIT                                  AS
   54 FØRMAT(1H0,5X,$NUMBER HITS$,3X,F6.0,5X,$NUMBER RØUNDS FIRED$,3X,  AS
     *F6.0,5X,$PERCENTAGE ØF HITS$,3X,F6.2)                             AS
      WRITE(108,55) RMIN,RMAX                                           AS
   55 FØRMAT(1H0,$RMIN=$,F10.2,5X,$RMAX=$,F10.2)                        AS
C                                                                       AS
C     CØMPUTE RANGE CELL SIZE                                           AS
C                                                                       AS
      RCELL=(RMAX-RMIN)/NCELLS                                          AS
C                                                                       AS
C     INITIALIZE CELL BØUNDARIES AND PLØT ØRDINATES                     AS
C                                                                       AS
      RLØW=RMIN                                                         AS
      RUP=RLØW+RCELL                                                    AS
      DØ 24 N=1,NCELLS                                                  AS
      ØRD=0.0                                                           AS
      ØRDN=0.0                                                          AS
      DØ 23 L=1,MISSCNT                                                 AS
C                                                                       AS
C     BYPASS IF WRØNG SPØTTING MØDE                                     AS
C                                                                       AS
```

```
      IF (MØDE(L) .NE. K) GØ TØ 23                                       AS
C                                                                        AS
C     BYPASS IF ØUT ØF RANGE CELL LIMITS                                 AS
C                                                                        AS
      IF(R4(L) .LT. RLØW .ØR. R4(L) .GE. RUP) GØ TØ 23                   AS
C                                                                        AS
C     ADD RANGE MISS DISTANCE TØ TØTAL AND INCREMENT CØUNT               AS
C                                                                        AS
      ØRD=ØRD+RMISS(L)                                                   AS
      ØRDN=ØRDN+1.0                                                      AS
   23 CØNTINUE                                                           AS
C                                                                        AS
C     SET AVERAGE RANGE MISS=100 IF NØ RØUNDS FIRED IN THIS CELL         AS
C                                                                        AS
      IF (ØRDN .EQ. 0.0) ØRDN=1.0; ØRD=100.                              AS
C                                                                        AS
C     CØMPUTE AND STØRE PLØT PØINTS                                      AS
C                                                                        AS
      XY(N,1)=RLØW                                                       AS
      XY(N,2)=ØRD/ØRDN                                                   AS
C                                                                        AS
C     INCREMENT CELL BØUNDARIES                                          AS
C                                                                        AS
      RLØW=RUP                                                           AS
   24 RUP=RLØW+RCELL                                                     AS
C                                                                        AS
C     PLØT RESULTS                                                       AS
C                                                                        AS
      CALL VPLØT(XY,JXY,NCELLS,NCELLS,1,0,XMIN,XMAX,YMIN,YMAX)           AS
   25 CØNTINUE                                                           AS
C                                                                        AS
C     RESET PRØBLEM FØR NEXT RUN                                         AS
C                                                                        AS
      IF(SENSE SWITCH 5) 100,26
   26 CØNTINUE
      END
```

```
      SUBROUTINE ADPSPOT
C.......................................................................
C     SUBROUTINE ADPSPOT CALLS FOR A RANDOM SPOT IF A TARGET          .
C     MANEUVER IS DETECTED, IF NOT NO SPOT.                           .
C.......................................................................
      COMMON /RELMOTION/ DRTX1, DRTY1, VOX, VOY, RX1, RY1, R1, T1
      COMMON /TRKTOADP/VELX1,VELX2,VELX3,VELX4,VELY1,VELY2,VELY3,VELY4
      DATA DETR/1.0/
C
C     ESTABLISH VELOCITY CHANGE CRITERIA
C
      TESTX1=ABS(VELX1-VELX2)
      TESTX2=ABS(VELX3-VELX4)
      TESTX3=ABS(VELX1-VELX2+VELX3-VELX4)
      TESTY1=ABS(VELY1-VELY2)
      TESTY2=ABS(VELY3-VELY4)
      TESTY3=ABS(VELY1-VELY2+VELY3-VELY4)
C
C     CHECK FOR MANEUVER AS DETECTED BY VELOCITY CHANGE
C
      IF(((TESTX1 .GE. DETR) .AND. (TESTX2 .GE. DETR) .AND. (TESTX3 .GE.
     *(2. * DETR ))) .OR. (( TESTY1 .GE. DETR ) .AND. (TESTY2 .GE.
     * DETR) .AND. ( TESTY3 .GE. (  2.*DETR)))) CALL RANDSPT;
     *CALL SETLINES(9,-1); GO TO 1
      CALL SETLINES(9,1)
C
C     BACKSLIDE VELOCITIES
C
    1 VELX3=VELX1
      VELX4=VELX2
      VELY3=VELY1
      VELY4=VELY2
      RETURN
      END
```

```
      SUBROUTINE GAUSS (S,AM,V)
C.....................................................................C
C     PURPOSE                                                         C
C          COMPUTES A NORMALLY DISTRIBUTED RANDOM NUMBER WITH A GIVEN  C
C          MEAN AND STANDARD DEVIATION.                               C
C     DESCRIPTION OF PARAMETERS                                       C
C          S - DESIRED STANDARD DEVIATION OF THE NORMAL DISTRIBUTION  C
C          AM- DESIRED MEAN OF THE NORMAL DISTRIBUTION                C
C          V - THE VALUE OF THE COMPUTED NORMAL RANDOM VARIABLE       C
C.....................................................................C
      A=0.0
      DO 1 I=1,12
      CALL RANDOM(W)
    1 A=A+W
      V=(A-6.0)*S+AM
      RETURN
      END
```

```
      SUBROUTINE MANEUVER(NIT,ITNOW)
C.........................................................................
C     SUBROUTINE MANEUVER CONTROL THE PT COURSE AND SPEED FOR A          .
C     PRE-PROGRAMMED RUN.                                                .
C.........................................................................
      DIMENSION ORDSP(4), ORDCO(5), NORDSP(44), NORDCO(44), NITNOW(44)
      DATA ORDSP/.3,.45,.6,.75/ORDCO/-.36,-.30,0.0,.30,.36/
      DATA NORDSP/44*1/
      DATA NORDCO/3,1,3,5/
      DATA NITNOW/1,15,21,36,48,63,77,92,108,123,135,150,158,173,184,
     *199,213,228,245,260,280,295,308,323,329,344,352,367,377,392,403,
     *418,430,445,466,481,511,526,549,564,580,595,611,700/
      I=NORDSP(NIT)
      J=NORDCO(NIT)
      SORDSP=ORDSP(I)
      SORDCO=ORDCO(J)
      CALL DAC(9,SORDSP,10,SORDCO)
      NIT=NIT+1
      ITNOW=NITNOW(NIT)
      RETURN
      END
```

```
      SUBROUTINE PLOOK (PART,R3,R3MAX,NO,R)
      DIMENSION PART(8)
C.......................................................................
C     SUBROUTINE PLOOK DETERMINES THE FOLLOWING                        .
C          1. WHICH RANGE SEGMENT (PARNO) THE TARGET IS IN.            .
C          2. MAGNITUDE OF RANGE FROM SEGMENT BOUNDARY TO TARGET (R).  .
C          3. BASE INDEX FOR TIME OF FLIGHT CALCULATIONS (NO).         .
C.......................................................................
C
C     DETERMINE RANGE SEGMENT
C
      IF (R3 .GE. R3MAX) R3=R3MAX; PARNO=8; GO TO 2
      DO 1 I=1,7
      J=8-I
    1 IF (R3 . GE. PART(J) ) PARNO=J; GO TO 2
C
C     DETERMINE MAGNITUDE OF RANGE FROM PARTITION BOUNDARY TO TARGET
C
    2 R=R3-PART(PARNO)
C
C     DETERMINE BASE INDEX FOR TOF CALCULATIONS
C
      NO=PARNO*4-3
      RETURN
      END
```

```
      SUBROUTINE RACT(ACTR,ACTSEG,RAC,NSF)
C..........................................................................
C              SUBROUTINE RACT DETERMINES THE ACTUAL RANGE OF THE TARGET    .
C         BY COMBINING THE SEGMENT NUMBER AND THE SEGMENT RANGE.            .
C..........................................................................
      DIMENSION PARSEG(10,1)
      DATA PARSEG/.79,.59,.39,.19,-.01,-.21,-.41,-.61,-.81,-1.0/
C
C     DETERMINE RANGE SEGMENT
C
      DO 1 I=1,10
    1 IF ( ACTR .GE. PARSEG(I,1) ) GO TO 2
C
C     CHECK FOR LOWER SEGMENT POSSIBILITY
C
    2 DIFF=ABS(ACTR-PARSEG(I,1))
      IF (DIFF .LE. .03 .AND. ACTSEG .GE. .8)
     *     NSF=10-I;
     *     GO TO 3
      NSF=11-I
C
C     COMPENSATE FOR QUADRANT SIGNS
C
    3 IF ( NSF .GE. 6 )
     *     RAC =(NSF+ACTSEG-6.0)*4000.0;
     *     RETURN
      RAC =(-NSF-ACTSEG+6.0)*4000.0
      RETURN
      END
```

```
      SUBROUTINE RANDOM (W)
C..............................................................................
C     SUBROUTINE RANDOM PRODUCES A UNIFORMLY DISTRIBUTED RANDOM NUMBER .
C     0 AND 1.                                                                 .
C..............................................................................
      DIMENSION R(30)
      DATA I/10/
      DATA  R/
     *   .150781319000088,   .914453206998587,   .514453231837251,
     *   .898828280478483,   .815625252795143,   .612891073171340,
     *   .838672715504799,   .397655462456896,   .273045296104100,
     *   .800387462008075,   .779681167623493,   .810924827368580,
     *   .094115270407201,   .029246154575957,   .416304796039185,
     *   .855265827125549,   .546078512492385,   .888641380963235,
     *   .682751490840018,   .528002958235447,   .623584015538654,
     *   .367871127691614,   .557617224250861,   .786328164656879,
     *   .241015667790634,   .295703170922934,   .698437549086520/
C     THESE VALUES WERE OBTAINED BY RUNNING THE OLD SELF-INITIALIZING
C     VERSION OF RANDOM 100 TIMES AND TAKING THE RESULTING VALUES IN R
C     THIS VERSION NEVER USES ITS ARGUMENT AS AN INPUT, AN ADDITIONAL
C     SAFEGUARD. RANDOM PRODUCES VALUES BETWEEN 0 AND 1.
    2 J=I
      I=I+1
      IF(I .GT. 30) I=1
      W=R(J)-R(I)
      IF(W .LE. 0.0) W=W+.999999999837
      R(I)=W
      RETURN
      END
```

```
      SUBRØUTINE RANDSPT
C.........................................................................
C     SUBRØUTINE RANDSPT ADDS A UNIFØRMLY DISTRIBUTED SPØT IN RANGE      .
C     AND A GAUSSIAN DISTRIBUTED SPØT IN BEARING.                        .
C.........................................................................
      CØMMØN /RELMØTIØN/ DRTX1, DRTY1, VØX, VØY, RX1, RY1, R1, T1
C
C     DETERMINE PT SPEED
C
      VPTX=DRTX1-VØX
      VPTY=DRTY1-VØY
      VPT=SQRT((VPTX**2)+(VPTY**2))
C
C     ADD UNIFØRM RANGE SPØT
C
      RSPØT=7.5*VPT+200.
      CALL RANDØM(W)
      R1=R1+RSPØT*(W-.5)
C
C     ADD GAUSSIAN SPØT IN BEARING
C
      BRNG=ATAN2(RY1,RX1)
      STDB=.0000837*VPT+.0025
      CALL GAUSS(STDB,BRNG,BY)
C
C     RESØLVE INTØ CARTESIAN CØØRDINATES
C
      RX1=R1*CØS(BY)
      RY1=R1*SIN(BY)
      RETURN
      END
```

```
      SUBROUTINE RDRNOISE(XACT,YACT,XNK,YNK,RDRRNG,AZ)
C.......................................................................
C     SUBROUTINE RDRNOISE TOGETHER WITH GAUSS ADDS NOISE TO THE RADAR  .
C          SIGNAL. THIS NOISE IS CORRECTED FOR RANGE AND AZ BINS.      .
C.......................................................................
      DATA PI/3.14159265/
C
C     DETERMINE AND ADD GAUSSIAN NOISE IN RANGE
C
      CALL GAUSS (4.0,0.0,RNOISE)
      RDRRNG=SQRT((XACT**2)+(YACT**2))+RNOISE
C
C     CORRECT FOR RANGE BIN ROUNDOFF
C
      M=RDRRNG/10.0
      RDRRNG=10*M+5
C
C     DETERMINE AND ADD GAUSSIAN NOISE TO BEARING
C
      CALL GAUSS(.002,0.0,BNOISE)
      AZ=ATAN2(YACT/XACT)+BNOISE
C
C     CORRECT FOR AZMIUTH BIN ROUNDOFF
C
      F=(2.0*PI)/8192.0
      M=AZ/F
      FM=M
      AZ=(FM+0.5)*F
C
C     CONVERT TO RECTANGULAR COORDINATES
C
      XNK=RDRRNG*COS(AZ)
      YNK=RDRRNG*SIN(AZ)
      RETURN
      END
```

```
      SUBROUTINE SPOTNORM(NRSPOT,NBSP)
C.............................................................................
C     SUBROUTINE SPOTNORM GENERATES A SPOTTING ROUTINE INCORPORATING        .
C          A RANGE AND DEFLECTION LADDER.                                   .
C.............................................................................
      COMMON /RELMOTION/ DRTX1, DRTY1, VOX, VOY, RX1, RY1, R1, T1
C
C     DETERMINE RANGE SPOT
C
      IF (NRSPOT .EQ. 1) RSPOT=100.; GO TO 1
      IF (NRSPOT .EQ. 2) RSPOT=0.0; GO TO 1
      IF (NRSPOT .EQ. 3) RSPOT=-100.0
C
C     DETERMINE BEARING SPOT
C
    1 IF (NBSP .EQ. 1) BSPOT=0.00490875; GO TO 2
      IF (NBSP .EQ. 2) BSPOT=0.0; GO TO 2
      IF (NBSP .EQ. 3) BSPOT=-0.00490875
C
C     ADD BEARING SPOT AND RANGE SPOT
C
    2 BRNG=ATAN2(RY1/RX1)
      R1=R1+RSPOT
      BRNG=BRNG+BSPOT
C
C     CONVERT TO RECTANGULAR COORDINATES
C
      RX1=R1*COS(BRNG)
      RY1=R1*SIN(BRNG)
      RETURN
      END
```

```
      SUBROUTINE TIMER(N)
C.......................................................................
C     SUBROUTINE TIMER SETS UP THE INITIAL CONDITIONS ON A 16 BIT       .
C     BINARY COUNTER SO THAT AFTER A DESIRED TIME HAS ELAPSED THE       .
C     COUNTER WILL BE FILLED AND TRIGGER THROUGH THE FINAL CARRY.       .
C.......................................................................
C
C     INHIBIT OUTPUT DURING SETUP
C
      CALL SETLINES(6,1)
C
C     CALCULATE INITIAL CONDITIONS FOR COUNTER
C
      NC1=65535-N
C
C     DECIMAL TO BINARY CONVERSION FOR INITIAL CONDITION
C
      DO 2 J=1,16
      NC2=NC1/2
      IF((NC1-(2*NC2)) .EQ. 1)
     *      LSET=-1;
     *      GO TO 1
      LSET=1
    1 NC1=NC2
    2 CALL SETLINES(9+J,LSET)
C
C     INITIALIZE COUNTER AND REMOVE INHIBIT SIGNAL
C
      CALL SETLINES(26,-1)
      CALL SETLINES(26,1,6,-1)
      RETURN
      END
```

```
      SUBROUTINE TRACKER(XNK,YNK,RDRRNG)
C.......................................................................
C     SUBROUTINE TRACKER INCORPORATES BOTH A LONG TERM AND SHORT TERM  .
C          TRACKER.  THE TRACKER SELECTION IS                          .
C              LESS THAN FOUR DATA POINTS - NO SOLUTION (NFLAG=1)      .
C              MORE THAN FOUR DATA POINTS                              .
C                    MANEUVER WAS NOT DETECTED - SHORT TERM TRACKER    .
C                                                  (NFLAG=2)           .
C                    MANEUVER WAS DETECTED - LONG TERM TRACKER(NFLAG=3).
C.......................................................................
      DIMENSION GP(30,2), GV(30,2), XI(40), YI(40), XS(4,4), YS(4,4)
      COMMON /RELMOTION/ DRTX1, DRTY1, VOX, VOY, RX1, RY1, R1, T1
      COMMON/TRKCOM/NN,NTRKS,NX,XSUM,TXSUM,YSUM,TYSUM,KPROC
      COMMON /TRKTOADP/VELX1,VELX2,VELX3,VELX4,VELY1,VELY2,VELY3,VELY4
      LOGICAL KPROC
C
C     POSITION FILTER GAIN SCHEDULE FIRST 30 RANGE LT 15K SECOND
C     RANGE GT 15K
C
      DATA GP/
     *0.999984, 0.636362, 0.633333, 0.605263, 0.552941, 0.498525,
     *0.449675, 0.407692, 0.371980, 0.341550, 0.315460, 0.292917,
     *0.273286, 0.256061, 0.240837, 0.227295, 0.215175, 0.204269,
     *0.194405, 0.185443, 0.177265, 0.169773, 0.162886, 0.156533,
     *0.150656, 0.145202, 0.140128, 0.135395, 0.130971, 0.126826,
     *0.999972, 0.587103, 0.562166, 0.555292, 0.523363, 0.481211,
     *0.439202, 0.401087, 0.367644, 0.338600, 0.313388, 0.291423,
     *0.272182, 0.255228, 0.240198, 0.226796, 0.214780, 0.203952,
     *0.194148, 0.185232, 0.177090, 0.169628, 0.162764, 0.156430,
     *0.150568, 0.145126, 0.140062, 0.135339, 0.130922, 0.126783/
C
C     VELOCITY FILTER GAIN SCHEDULE FIRST 30 RANGE LT 15K SECOND
C     RANGE GT 15K.
C
      DATA GV/
     *0.000000, 0.272729, 0.300000, 0.236842, 0.176470, 0.132743,
```

```
     *0.102272, 0.080769, 0.065217, 0.053678, 0.044910, 0.038106,
     *0.032727, 0.028405, 0.024881, 0.021973, 0.019544, 0.017496,
     *0.015753, 0.014257, C.012965, 0.011840, 0.010855, 0.009988,
     *0.009211, 0.008539, 0.007930, 0.007384, 0.006892, 0.006448,
     *0.000000, 0.174218, 0.228834, 0.203528, 0.161681, 0.125817,
     *0.098781, 0.078882, 0.064133, 0.053022, 0.044496, 0.037834,
     *0.032543, 0.028277, 0.024790, 0.021906, 0.019495, 0.017458,
     *0.015724, 0.014235, 0.012947, 0.011826, 0.010844, 0.009979,
     *0.009214, 0.008533, 0.007925, 0.007380, 0.006889, 0.006445/
      DATA XS,YS,XSUM,YSUM,TXSUM,TYSUM,NN,NX,NTRKS/34*0.0,3*0/
C
C     LIMIT GAIN SCHEDULE TØ 30; INCREMENT CØUNTERS; AND RESET TRACKER
C
      IF(NX .EQ. 30) NX=29
      NX=NX+1
      NFLAG=2
      NTRKS=NTRKS+1
      XS(1,1)=XNK
      YS(1,1)=YNK
C
C     SHØRT TERM TRACKER
C          TEST FØR RANGE BAND
C
      IF (RDRRNG .LT. 15000.) NBAND=1; DETR=60.0
      IF (RDRRNG .GE. 15000.) NBAND=2; DETR=65.
C
C          DETERMINE IF REPRØCESSING IS NECESSARY, SKIP IF NTRKS LT 4
C
      IF (NTRKS .LT. 4) GØ TØ 3
      TESTX1=ABS(XS(1,1)-XS(2,4))
      TESTX2=ABS(XS(2,1)-XS(3,4))
      TESTX3=ABS(XS(1,1)-XS(2,4)+XS(2,1)-XS(3,4))
      TESTY1=ABS(YS(1,1)-YS(2,4))
      TESTY2=ABS(YS(2,1)-YS(3,4))
      TESTY3=ABS(YS(1,1)-YS(2,4)+YS(2,1)-YS(3,4))
      IF(((TESTX1 .GE. DETR) .AND. (TESTX2 .GE. DETR) .AND. (TESTX3 .GE.
```

```
     *(2. * DETR ))) .OR. (( TESTY1 .GE. DETR ) .AND. (TESTY2 .GE.
     * DETR) .AND. ( TESTY3 .GE. (  2.*DETR)))) GO TO 1
      GO TO 3
C
C          REPROCESSING
C
    1 NX=1
      DO 2 M1=1,2
      M=4-M1
      XS(M,2)=XS(M,4)+GP(NX,NBAND)*(XS(M,1)-XS(M,4))
      XS(M,3)=XS(M+1,3)+GV(NX,NBAND)*(XS(M,1)-XS(M,4))
      XS(M-1,4)=XS(M,2)+XS(M,3)
      YS(M,2)=YS(M,4)+GP(NX,NBAND)*(YS(M,1)-YS(M,4))
      YS(M,3)=YS(M+1,3)+GV(NX,NBAND)*(YS(M,1)-YS(M,4))
      YS(M-1,4)=YS(M,2)+YS(M,3)
    2 NX=NX+1
      KPROC=.TRUE.
C
C          FILTER AND PREDICT
C
    3 XS(1,2)=XS(2,4)+GP(NX,NBAND)*(XS(1,1)-XS(2,4))
      XS(1,3)=XS(2,3)+GV(NX,NBAND)*(XS(1,1)-XS(2,4))
      VELX1=XS(1,3)
      XS(1,4)=XS(1,2)+XS(1,3)
      YS(1,2)=YS(2,4)+GP(NX,NBAND)*(YS(1,1)-YS(2,4))
      YS(1,3)=YS(2,3)+GV(NX,NBAND)*(YS(1,1)-YS(2,4))
      VELY1=YS(1,3)
      YS(1,4)=YS(1,2)+YS(1,3)
C
C          BACKFILE ALL QUANTITIES BY ONE OBSERVATION
C
      DO 4 M1=1,4
      M=5-M1
      DO 4 N1=1,3
      N=5-N1
      XS(N,M)=XS(N-1,M)
```

```
    4 YS(N,M)=YS(N-1,M)
C
C     LØNG TERM TRACKER
C
      NN=NN+1
      IF (NTRKS .GE. 41) GØ TØ 5
      NFLAG=2
C
C           ADD CURRENT ØBSERVATIØN TØ ARRAY
C
      TXSUM=TXSUM+XSUM
      XSUM=XSUM+XS(1,1)
      XI(NN)=XS(1,1)
      VELX2=XS(3,3)
      TYSUM=TYSUM+YSUM
      YSUM=YSUM+YS(1,1)
      YI(NN)=YS(1,1)
      VELY2=YS(3,3)
      GØ TØ 6
C
C           ADD CURRENT PØSITIØN TØ LØNG TERM TRACKER
C
    5 IF (NN .EQ. 41) NN=1
      TXSUM=TXSUM-(40. * XI(NN)) + XSUM
      XSUM=XSUM+XS(1,1)-XI(NN)
      XI(NN)=XS(1,1)
      TYSUM=TYSUM-(40. * YI(NN)) + YSUM
      YSUM=YSUM+YS(1,1)-YI(NN)
      YI(NN)=YS(1,1)
      XPLT=((20540. * XSUM) - (780. * TXSUM))/213200.0
      XVLT=((780. * XSUM) - (40. * TXSUM))/213200.0
      VELX2=XVLT
      YPLT=((20540. * YSUM) - (780. * TYSUM))/213200.0
      YVLT=((780. * YSUM) - (40. * TYSUM))/213200.0
      VELY2=YVLT
    6 IF(KPRØC .AND. NX .LT. 9) NFLAG=3; GØ TØ 8
```

```
  IF(KPRØC .AND. NX .EQ. 9) KPRØC=.FALSE.; GØ TØ 7
  IF (NTRKS .LT. 4) NFLAG=1
  IF (NFLAG .EQ. 1)
 *      CALL SETLINES(4,-1,5,1);
 *      RX1=23000.;
 *      RY1=23000;
 *      GØ TØ 9
7 IF (NFLAG .EQ. 2)
 *      CALL SETLINES (4,1,5,1);
 *      RX1=XS(2,2);
 *      RY1=YS(2,2);
 *      DRTX1=XS(2,3);
 *      DRTY1=YS(2,3);
 *      GØ TØ 9
8 IF (NFLAG .EQ. 3)
 *      CALL SETLINES (4,1,5,-1);
 *      RX1=XS(2,2);
 *      RY1=YS(2,2);
 *      DRTX1=XVLT;
 *      DRTY1=YVLT
9 R1=SQRT((RX1**2)+(RY1**2))
  RETURN
  END
```

```
      SUBROUTINE WRCIRCLE(ROTT)
C.......................................................................
C     SUBROUTINE WRCIRCLE DETERMINES THE RANGE TO THE CENTER OF THE    .
C     W R CIRCLE.                                                      .
C.......................................................................
      COMMON /RELMOTION/ DRTX1, DRTY1, VOX, VOY, RX1, RY1, R1, T1
      DATA A/400.66/B/-6.66/
C
C     DETERMINE POLAR VELOCITY FOR OWN SHIP
C
      VO=SQRT((VOX**2)+(VOY**2))
C
C     DETERMINE W R CIRCLE CENTER OFFSET COMPONENTS FOR OWN SHIP
C
      CO=ATAN2(VOY,VOX)
      OFFSET=A*VO+B
      XOFF=OFFSET*SIN(CO)
      YOFF=OFFSET*COS(CO)
C
C     DETERMINE RANGE TO CENTER OF THREAT ENVELOPE
C
      OTTX=RX1+XOFF
      OTTY=RY1+YOFF
      ROTT=SQRT ((OTTX**2)+(OTTY**2))
      RETURN
      END
```

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13. ABSTRACT

A real-time hybrid computer simulation was constructed for the study of fire-control pattern effectiveness in the defense of a destroyer against PT-boat attack. Different spotting procedures were tried over a repeatable maneuvering and non-maneuvering track in order to evaluate the relative results. The simulation also had a two-player gaming capability in order to evaluate the spotting procedures under full-scale evasion tactics. It was found that normal dispersion is more effective than random area fire for a low-speed maneuvering target, but area fire was more effective for a high-speed maneuvering target, with a random area fire the most effective.

Security Classification

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